NIST Response to the World Trade Center Disaster

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Visiting Committee on Advanced Technology

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National Context

- The collapse of the World Trade Center structures following the terrorist attacks of September 11, 2001 was one of the worst-ever building disasters in recorded history – killing 2749 people.
- More than 400 fire and emergency responders were among those killed, the largest loss of life for this group in a single incident.
- Strong private sector, public, and Congressional demand for a comprehensive response to the World Trade Center disaster.
- Congress passed and the President signed into law on October 1, 2002, the National Construction Safety Team (NCST) Act.
    - Gives NIST authorities to investigate building failures.
    - Modeled after the NTSB, with some differences.

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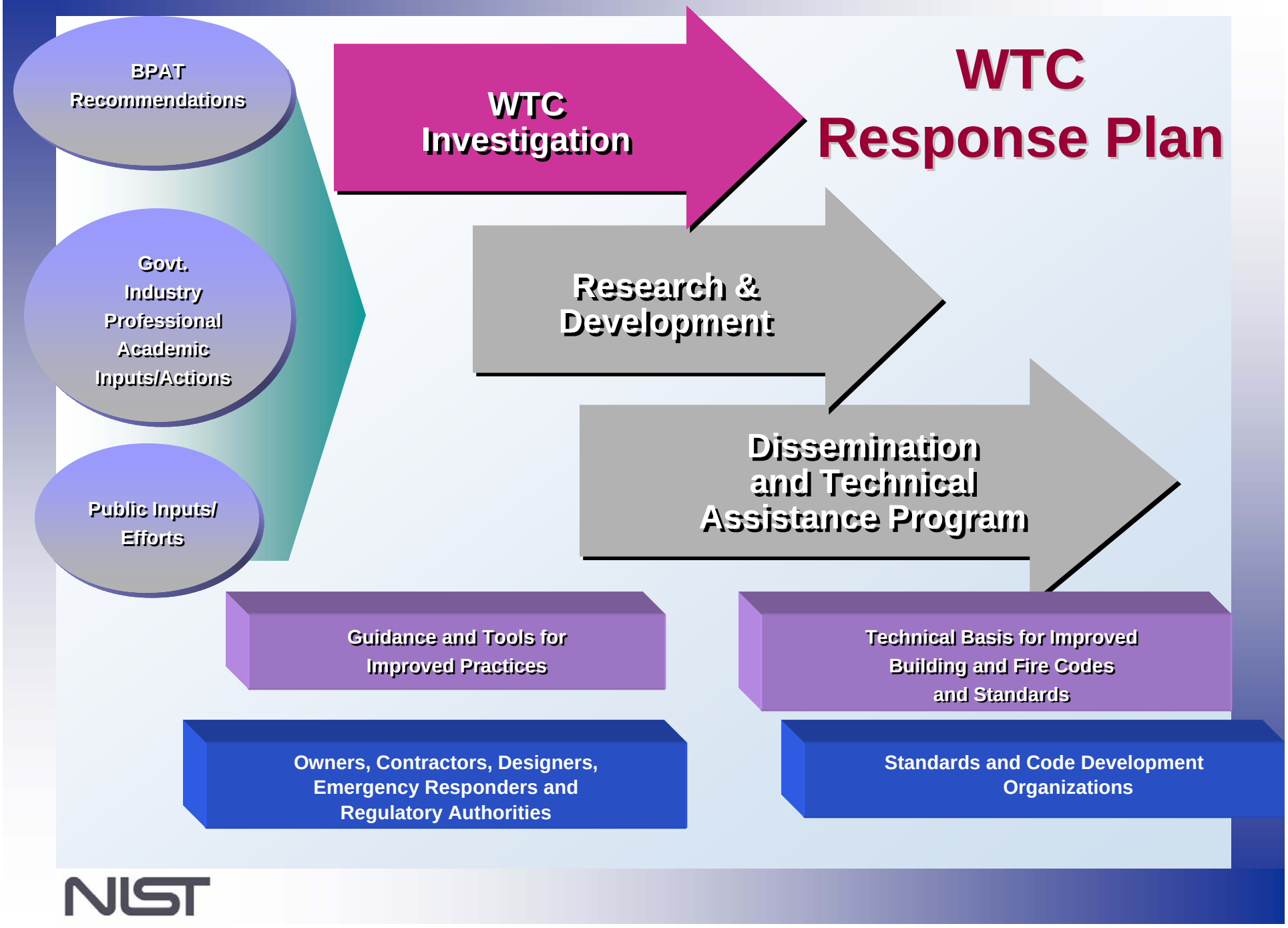
WTC Response Plan



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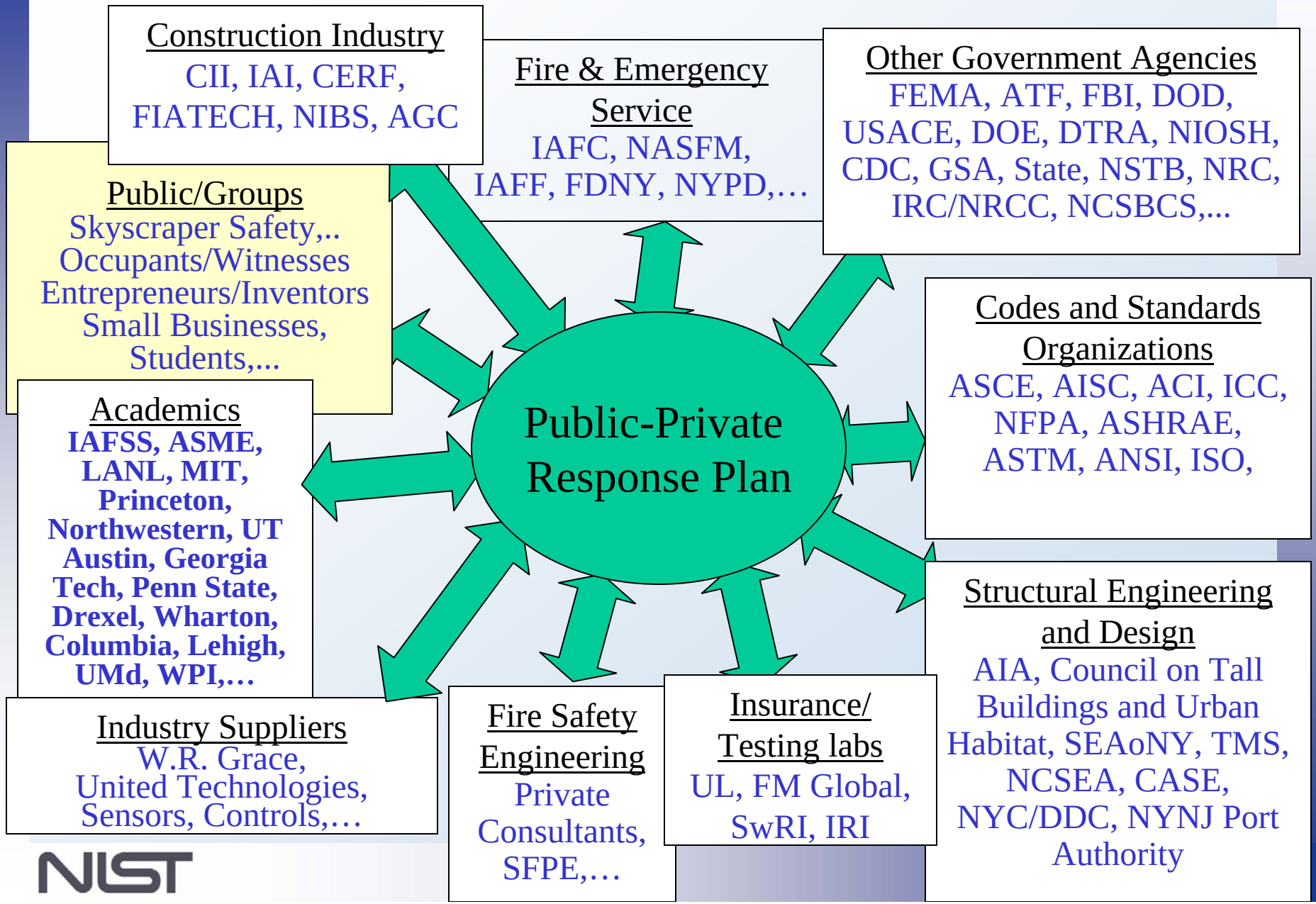
Stakeholders and Partners



Enabling Actions

- **NIST Actions:**
  - NIST Director established a World Trade Center study secretariat early in 2002—six months prior to formal announcement of the investigation—to ensure that relevant offices throughout NIST—public affairs, legal, contracts, congressional, budget, safety, program office—would all work to effectively support the investigation.
  - NIST Director selected a new 5-year project on “Failure Analysis of Complex Systems” for funding from proposals submitted to the highly competitive NIST-wide competence program.
- **Administration Actions:**
  - Requested $16 million funding for the WTC investigation.
  - Requested funding increases for the WTC R&D and DTAP programs ($ 3 million in FY 2003, $4 million in FY 2004 and FY 2005, $2 million in FY 2006).
- **Congressional Actions:**
  - House Science Committee held two standing-room only hearings in Spring 2002.
  - Appropriated funds for the WTC investigation ($16 million) and for the WTC R&D and DTAP programs ($3 million increase in FY 2003).
  - Passed the National Construction Safety Team Act (P.L. 107-231), which was signed into law on October 1, 2002.

NCST Advisory Committee

- Appointed by the NIST Director.
- Functions…
  - Review procedures and reports
  - Evaluate activities of teams
  - Assess implementation of recommendations
  - Annual report to Congress
- Reviewed WTC Investigation plan, progress, findings, and draft recommendations at 6 meetings.
- Reviewed all WTC progress reports and final reports
- Membership balances broad scope of disciplines and interests

Members

Dr. Charles Thornton, Co-Chairman, Thornton-Tomasetti.

Dr. Robert Hanson, Professor Emeritus, University of Michigan.

Mr. Philip DiNenno, President, Hughes Associates.

Professor Glenn Corbett, John-Jay College, NYC.

Dr. Kathleen Tierney, University of Colorado, Boulder.

Mr. Paul Fitzgerald, FM Global, (retired).

Mr. David Collins, The Preview Group.

Professor Forman Williams, University of California at San Diego.

Dr. John Barsom, President, Barsom Consulting.

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NIST WTC Investigation Objectives

- Determine:
  - why and how the WTC Towers collapsed following the initial impact of the aircraft, and
  - why and how the 47-story WTC 7 collapsed
- Determine why the numbers of injuries and fatalities were so low or high depending on location, including technical aspects of fire protection, occupant behavior, evacuation, and emergency response
- Determine the procedures and practices that were used in the design, construction, operation, and maintenance of the WTC buildings
- **Identify, as specifically as possible, areas in current national building and fire model codes, standards, and practices that warrant revision**

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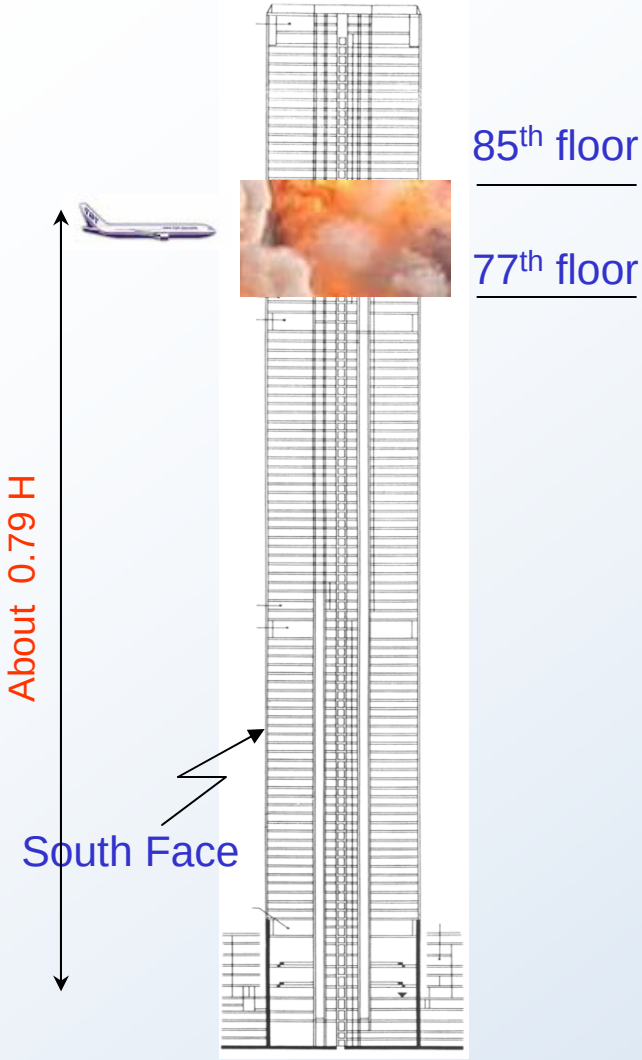
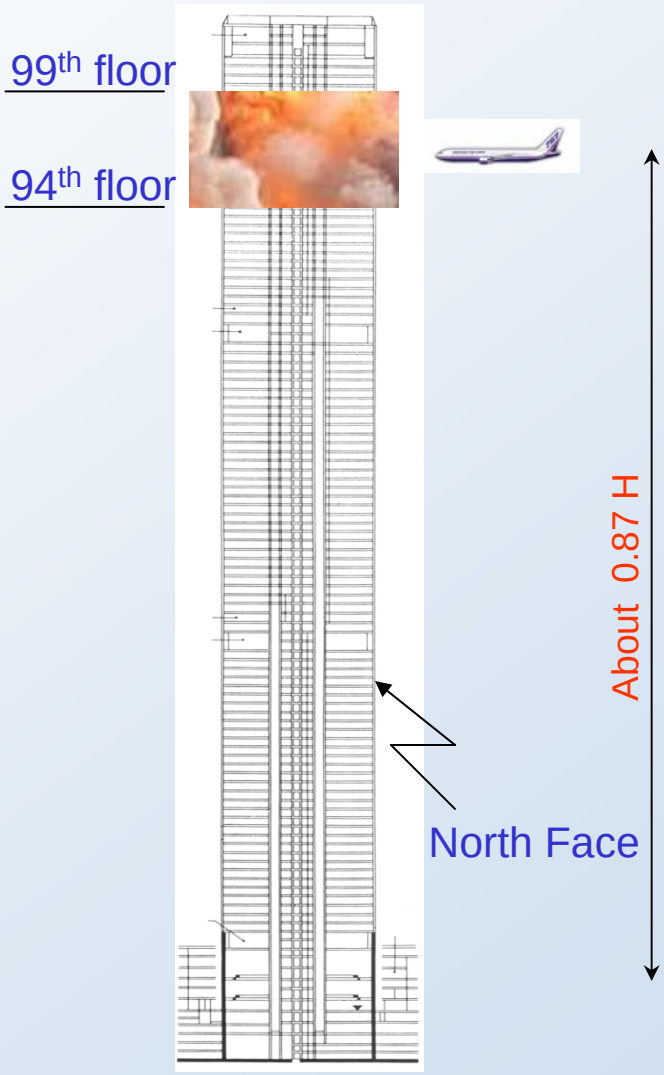


WTC 2: Hit at 9:02:59 AM
Collapsed after 56 minutes



WTC 1: Hit at 8:46:30 AM
Collapsed after 102 minutes

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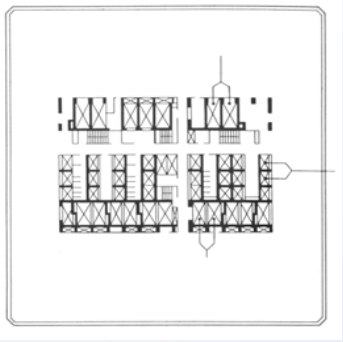
Point of impact: close to the center and nearly normal to the building



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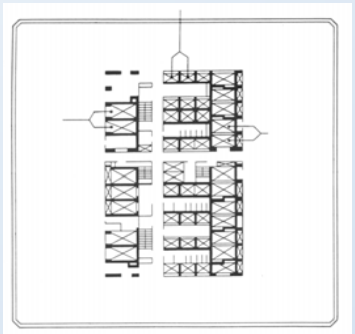
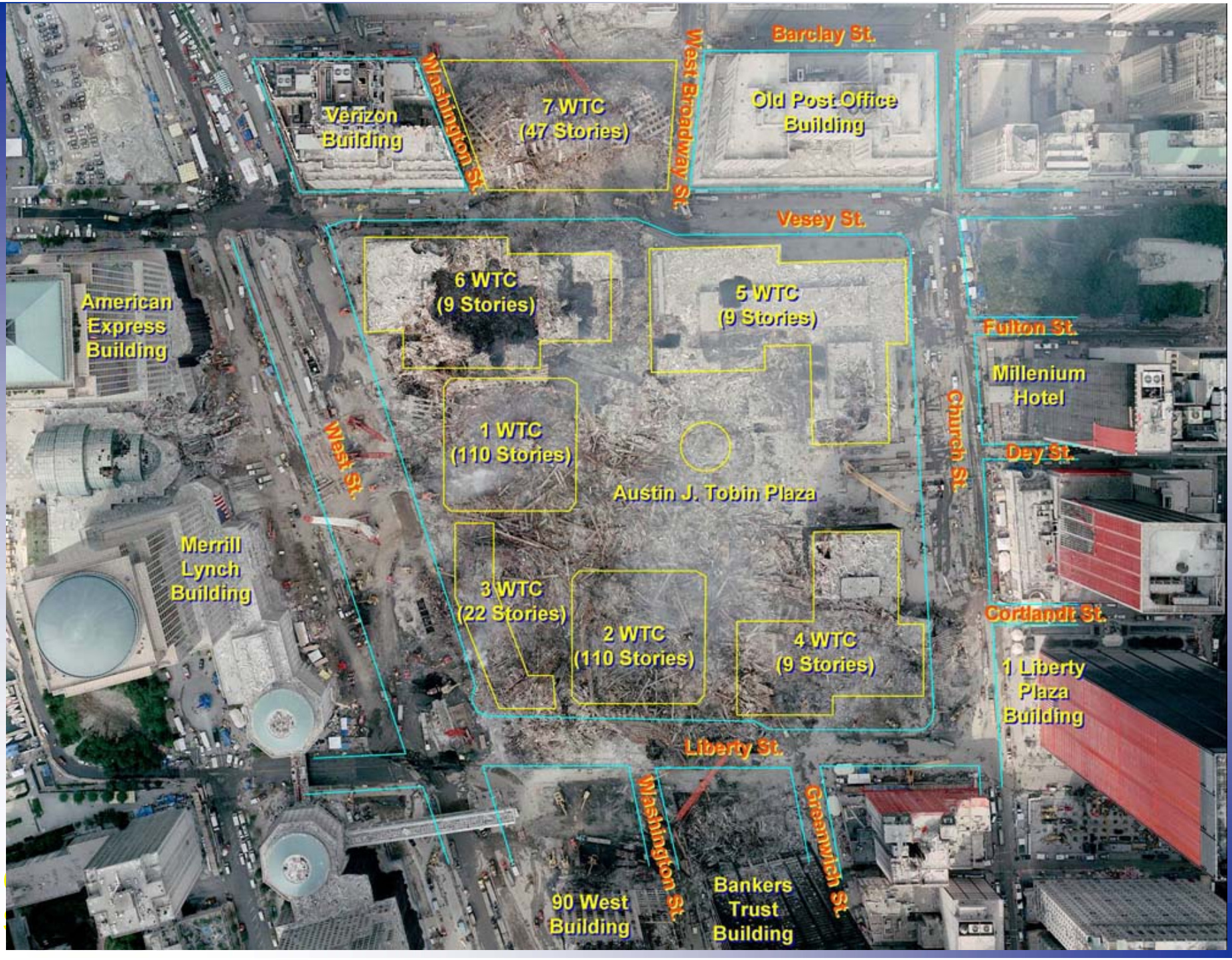
WTC 1

WTC 2



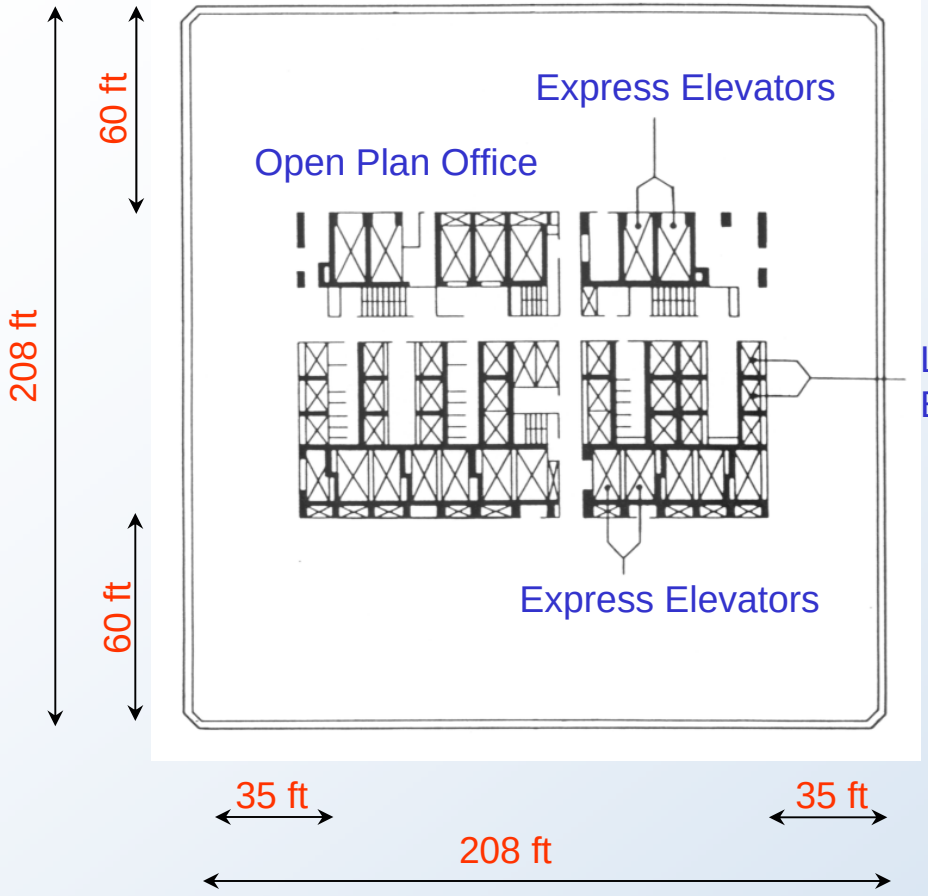
Point of impact: close to the corner and with an angle


Barclay St.
Verizon Building
Washington St.
7 WTC (47 Stories)
West Broadway St.
Old Post Office Building
Vesey St.
6 WTC (9 Stories)
5 WTC (9 Stories)
American Express Building
Fulton St.
Millenium Hotel
Church St.
1 WTC (110 Stories)
West St.
Austin J. Tobin Plaza
Dey St.
Merrill Lynch Building
3 WTC (22 Stories)
2 WTC (110 Stories)
4 WTC (9 Stories)
Cortlandt St.
1 Liberty Plaza Building
Liberty St.
Washington St.
Greenwich St.
90 West Building
Bankers Trust Building

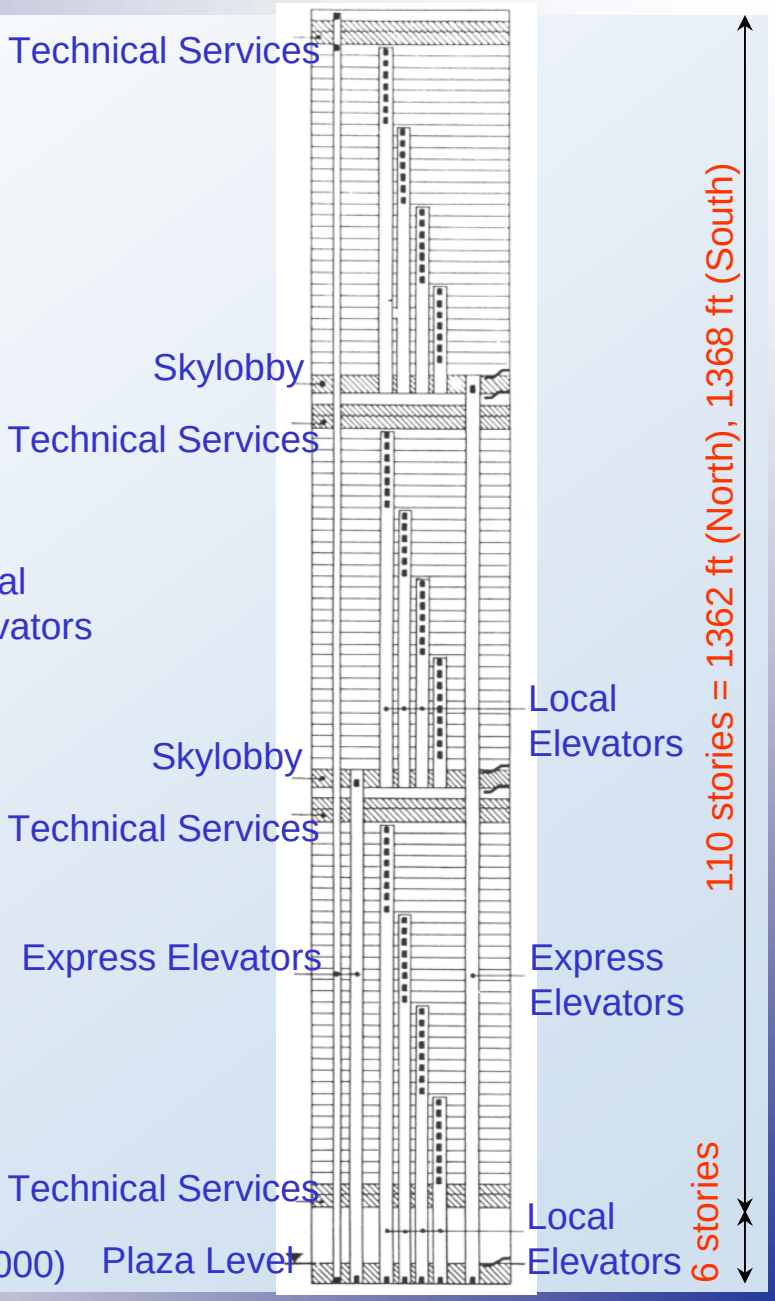
Some Specific Questions

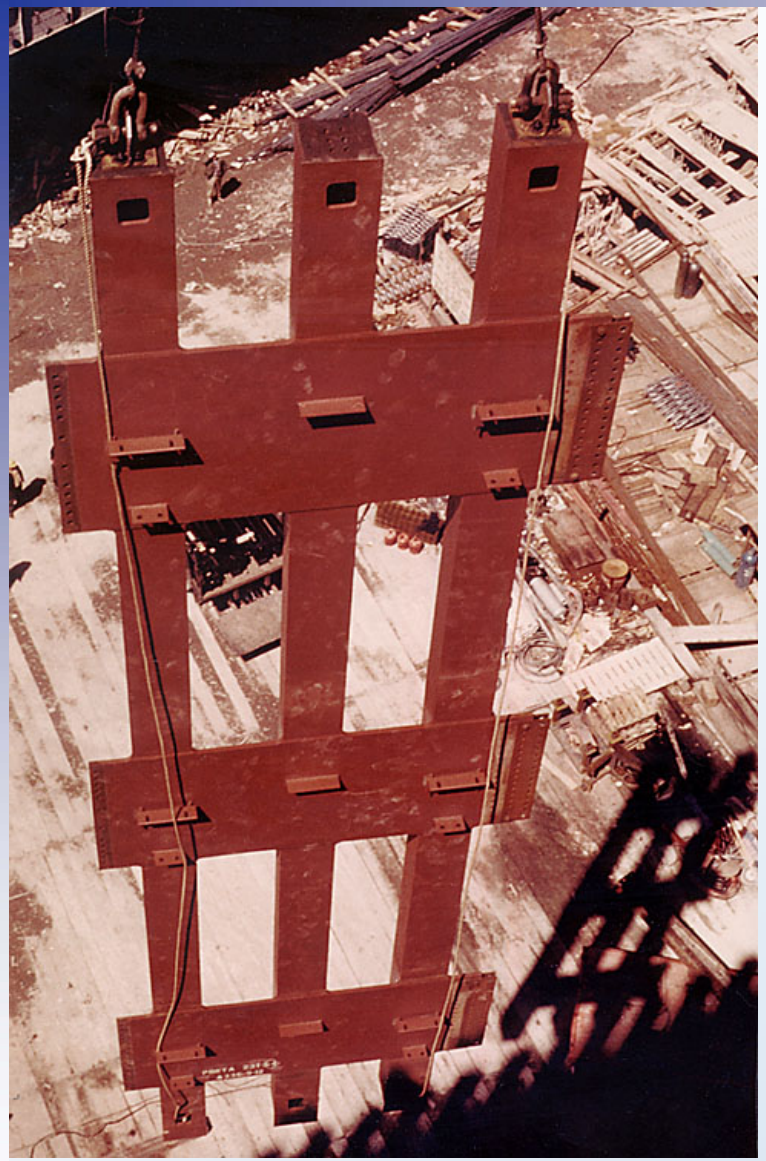
- How and why did WTC 1 stand nearly **twice** as long as WTC 2 before collapsing (102 min. vs. 56 min.) though they were hit by virtually identical aircraft?
- What factors related to **normal** building and fire safety considerations not unique to the terrorist attacks of September 11, 2001, if any, could have delayed or prevented the collapse of the WTC towers?
- Would the undamaged WTC towers have remained standing in a **conventional** large building fire scenario?
- What factors related to **normal** building and fire safety considerations, if any, could have saved additional WTC occupant lives or could have minimized the loss of life among the ranks of first responders?
- How well did the procedures and practices used in the design, construction, operation, and maintenance of the WTC buildings **conform** to accepted national practices, standards, and codes?

System Design Concept



Underground
Car Park
(total capacity 2000)





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Available Information on Safety of WTC Towers in Aircraft Collision (1)

Type of Aircraft:	Boeing 707 (largest jet aircraft in the air at that time) DC-8
Speed of Aircraft:	600 mph (Port Authority, February 1964) 180 mph (FEMA 403, 2002)
Location of Impact:	80th floor (Port Authority, March 1964)
Structural design:	It appears that the design of the WTC towers considered the impact of 707 aircraft and **analysis** indicated that such collision would result in only local damage which could not cause collapse or substantial damage to the building

NIST found no documentary evidence of any analysis supporting this conclusion.

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Available Information on Safety of WTC Towers in Aircraft Collision (2)

Fire safety: There are two views on whether the effect of jet fuel and aircraft contents was a consideration in the original building design:

- One view suggests that an analysis was done indicating the biggest problem would be the fact that all the fuel would dump into the building and there would be a horrendous fire.
- Another view suggests that the fuel load, and the fire damage that it would cause, may not have been considered.

Life safety: There are two views on what would be the effect of aircraft impact on occupant life safety.

- One view, which did not consider the fires, suggests that the aircraft impact would not have endangered the lives and safety of occupants not in the immediate area of impact
- Another view, which considered the fires, recognized that many people would not survive even though the building structure would remain.

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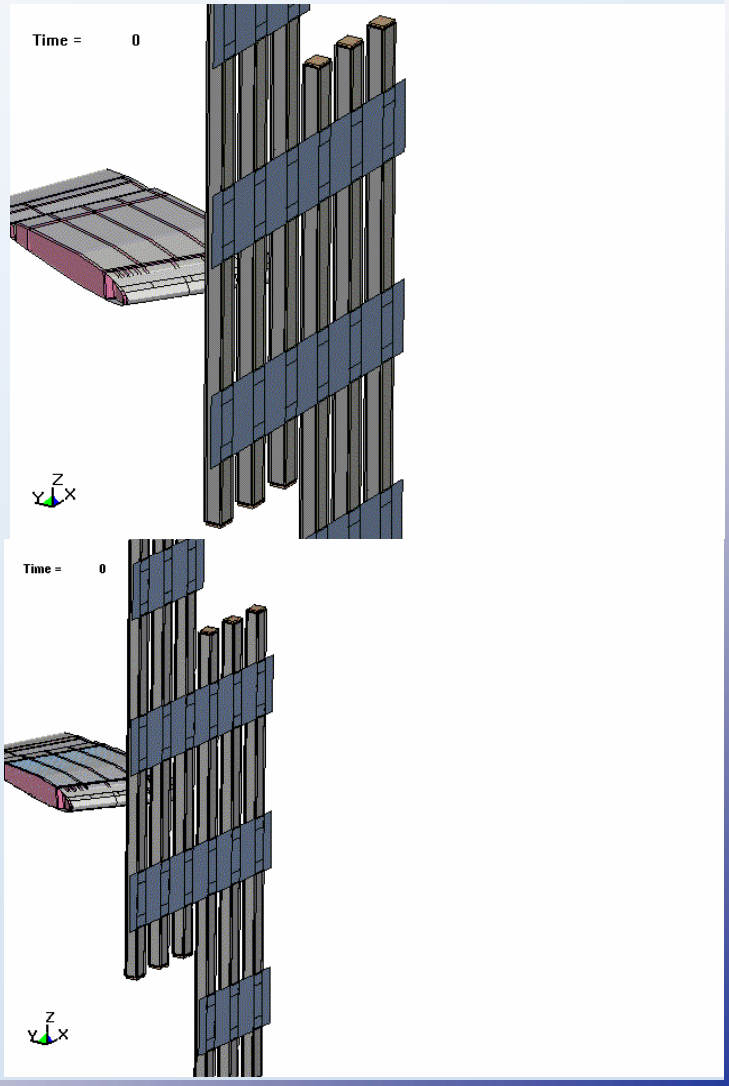
Preliminary Aircraft Impact Damage Analysis

- The impact of the exterior wall by an empty wing segment produces significant damage to the perimeter columns, not necessarily complete failure.
- The impact of a fuel-filled wing section results in extensive damage to the exterior wall panel, including complete failure of the perimeter columns.



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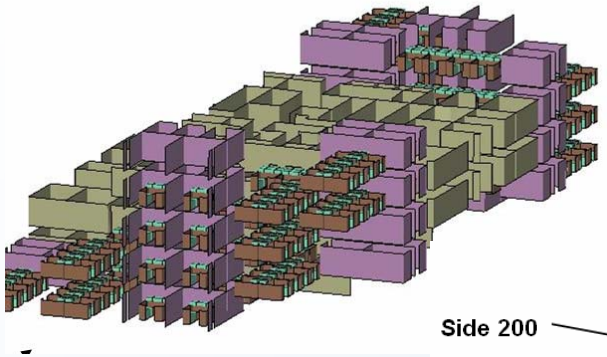
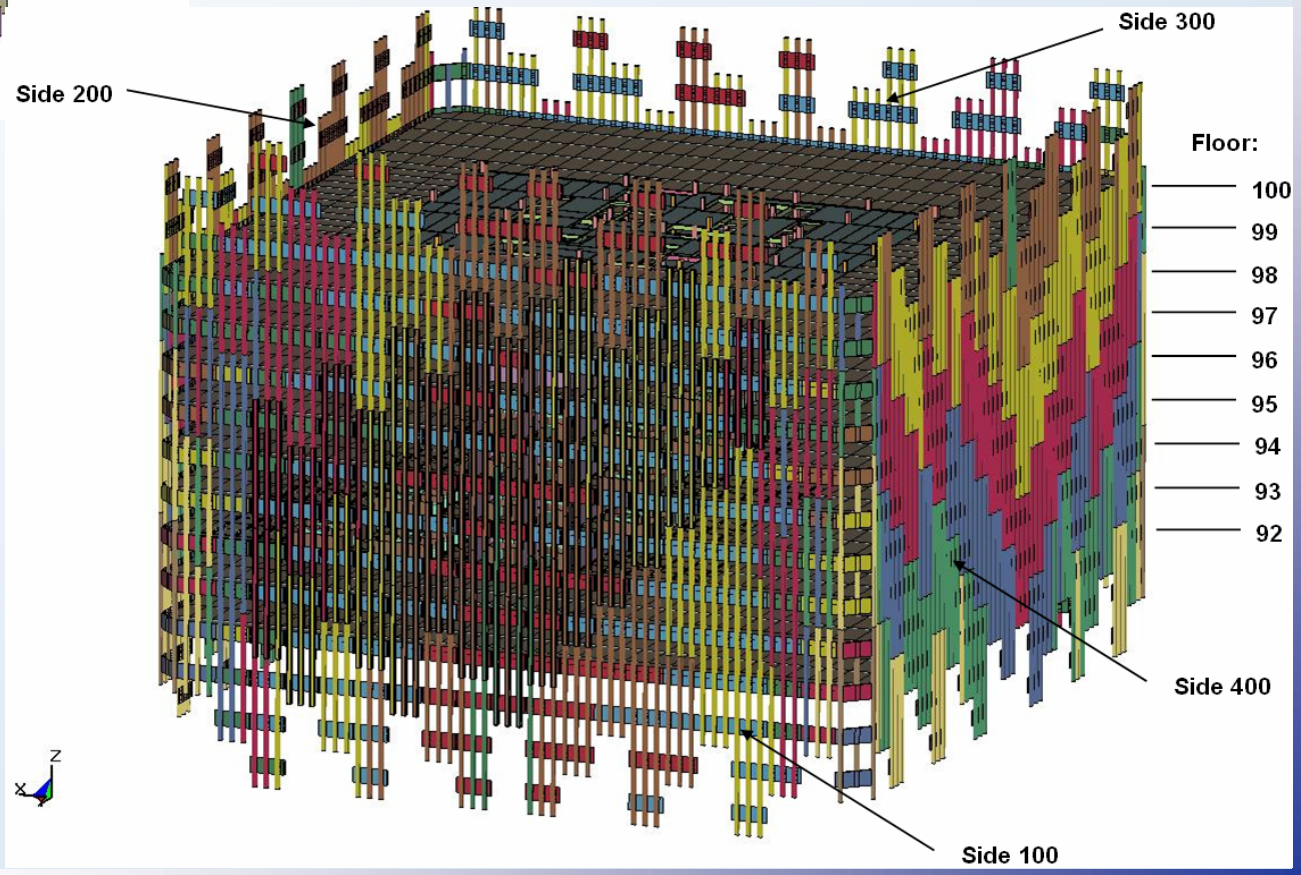
WTC 1 Tower Model for Aircraft Impact Analysis





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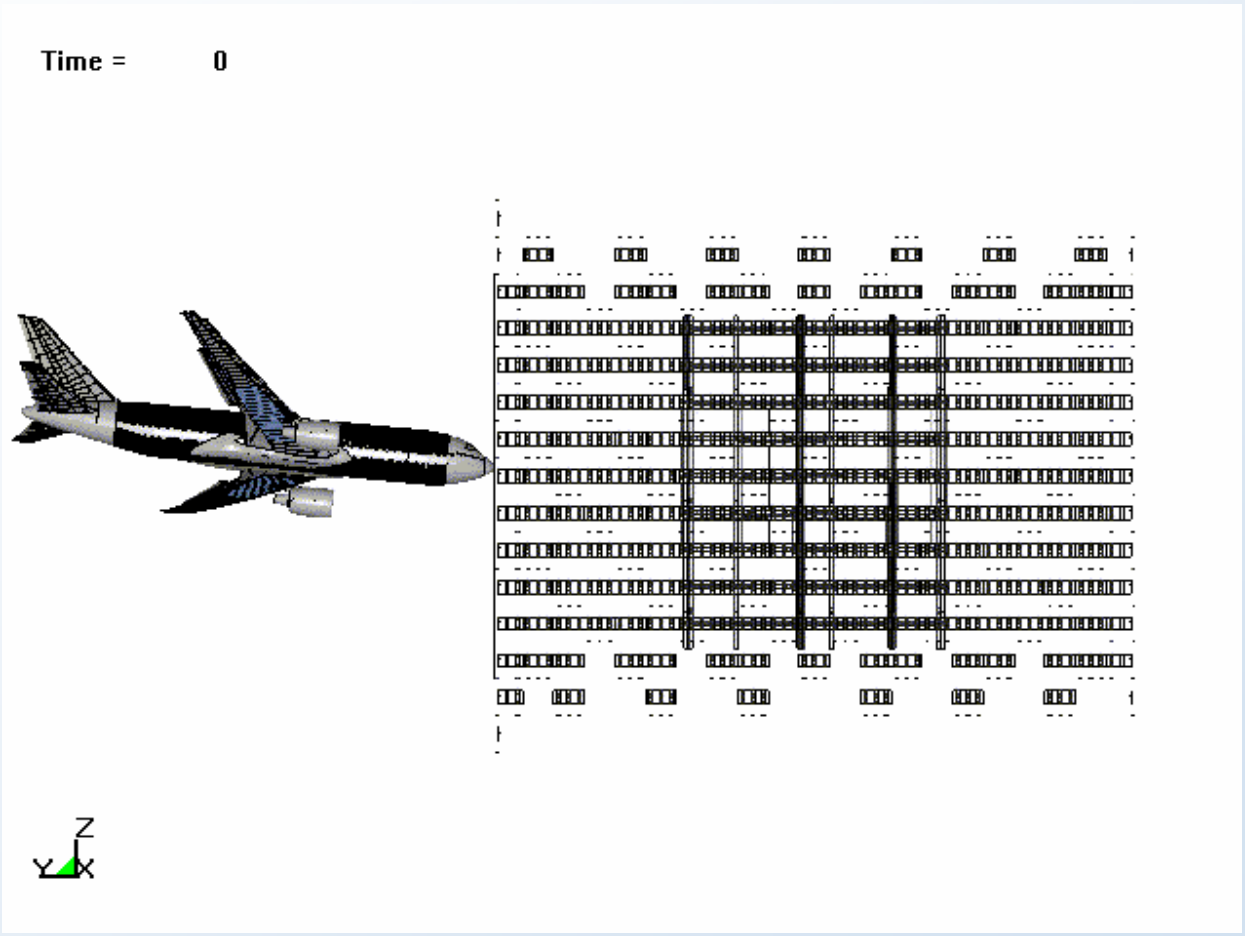
WTC 1 Severe Case



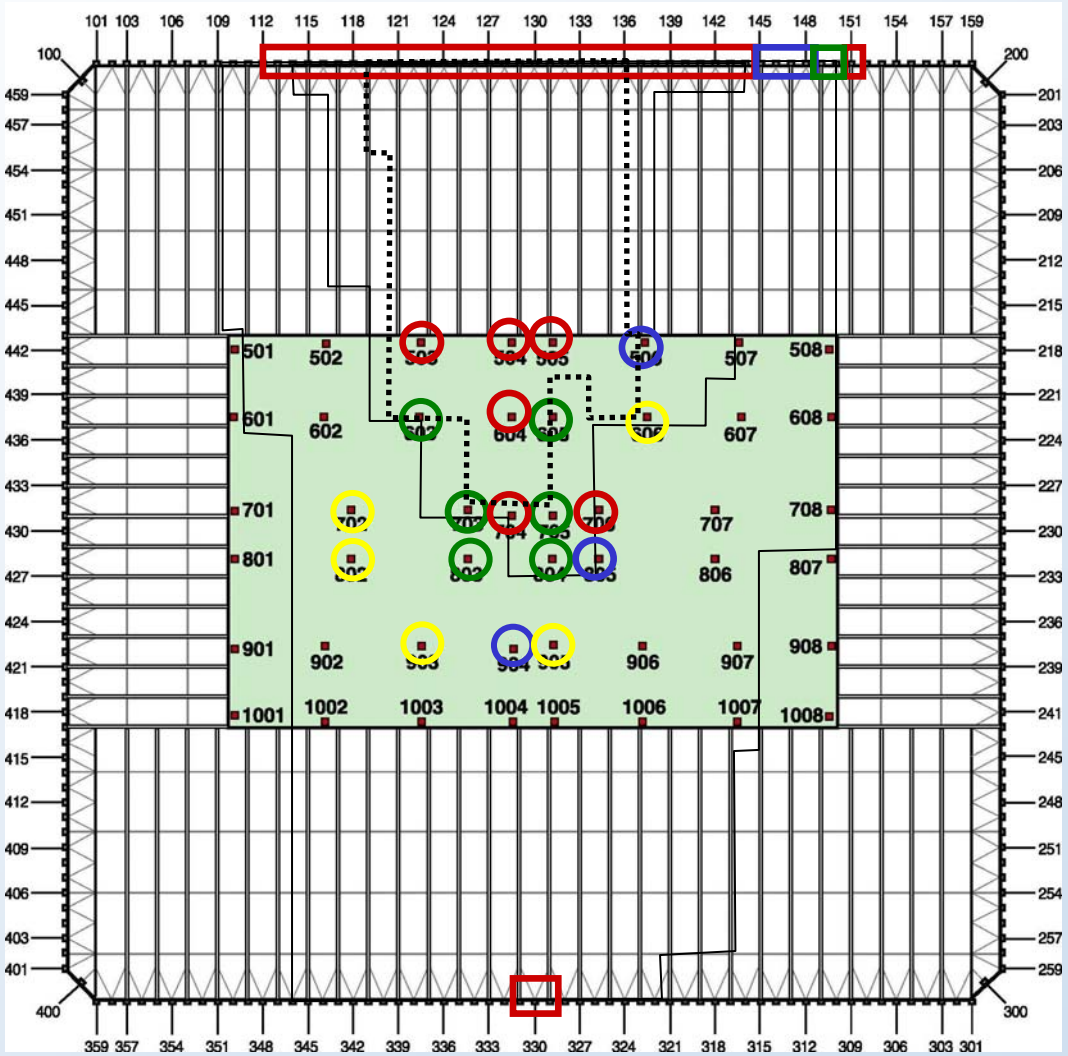
WTC 1 Damage for Severe Case: Composite Summary for Floors 93 to 98

Severe Floor Damage

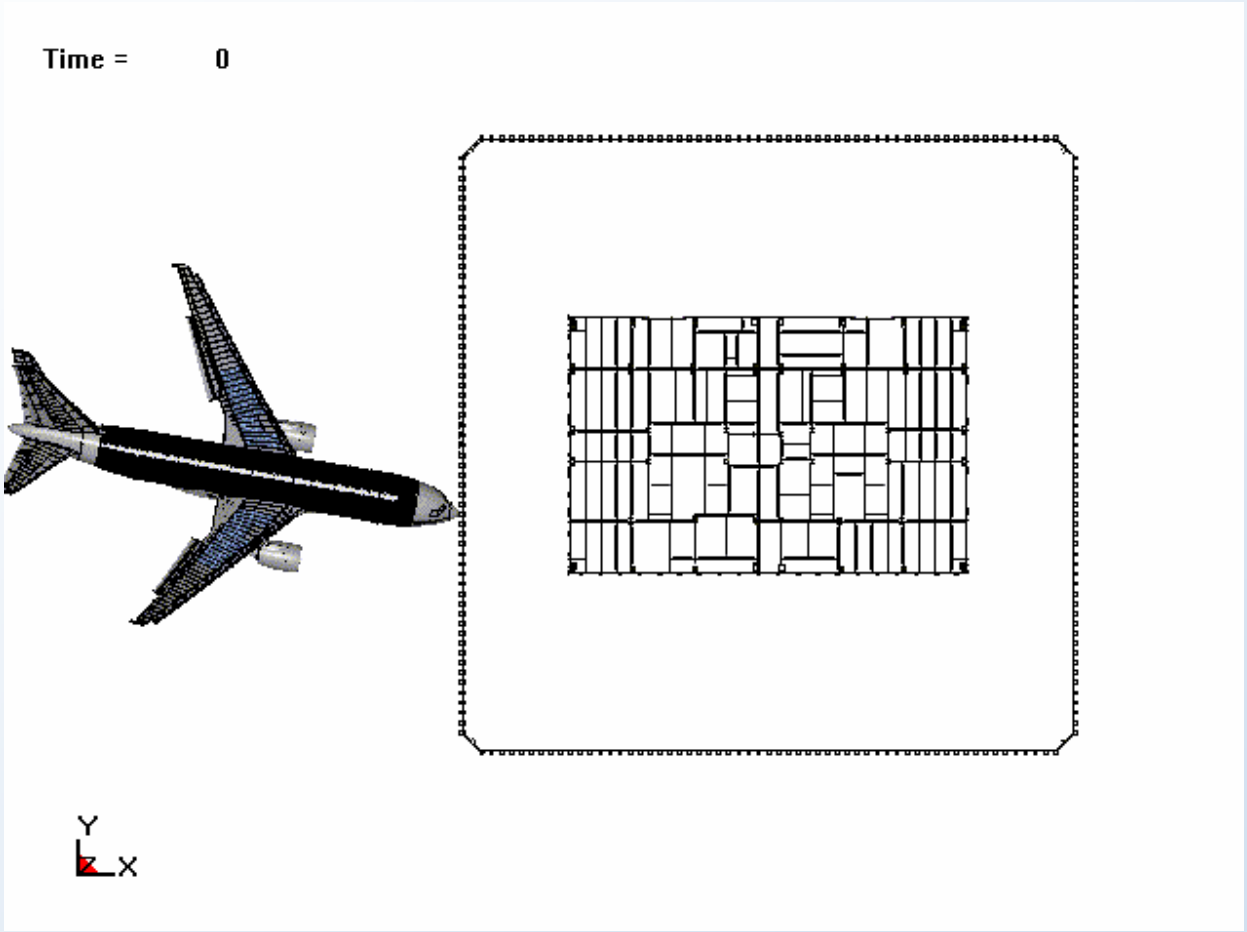
- Fireproofing (SFRM) and partitions
- Floor system structural damage
- Floor system removed

Column Damage

- Severed
- Heavy Damage
- Moderate Damage
- Light Damage



WTC 2 Severe Case



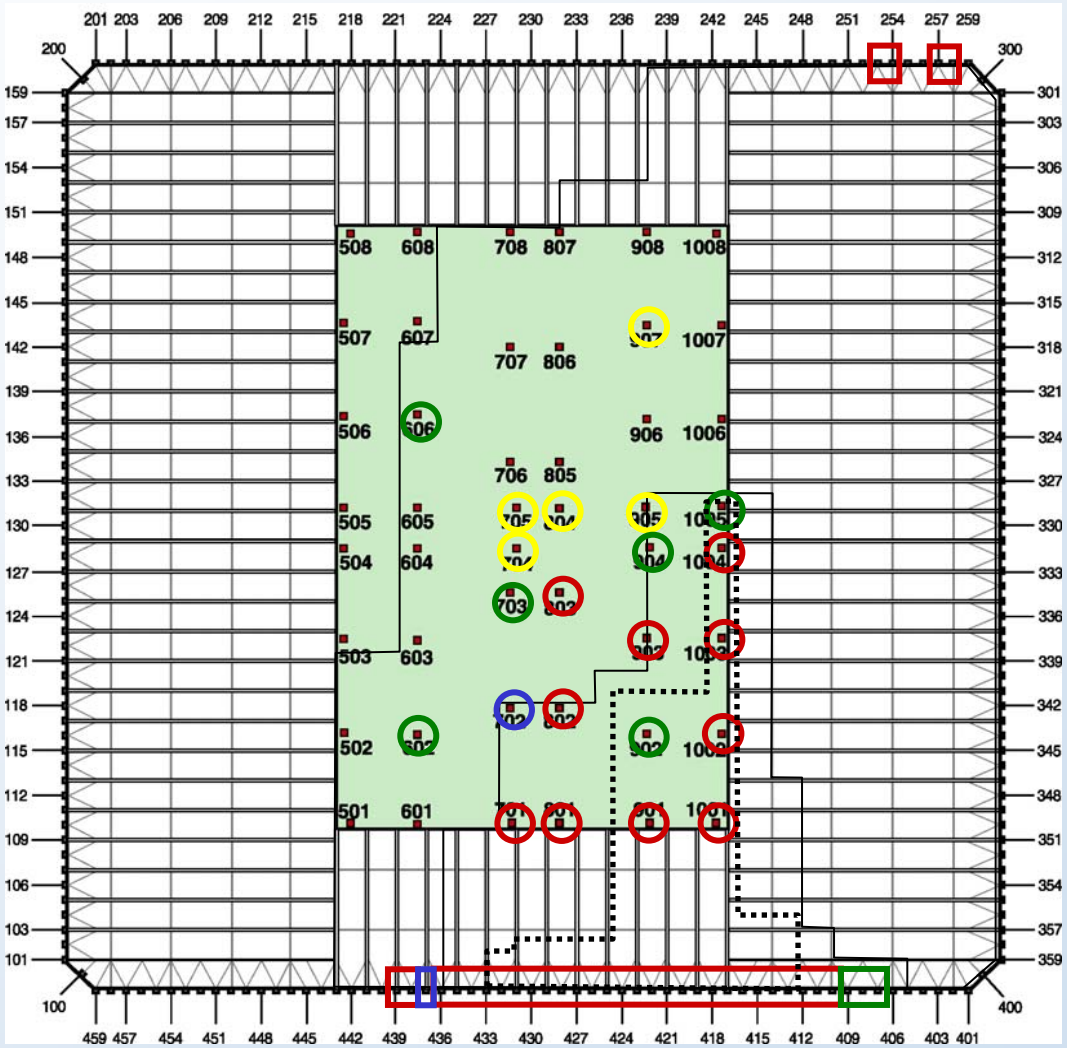
WTC 2 Damage for Severe Case: Composite Summary for Floors 78 to 83

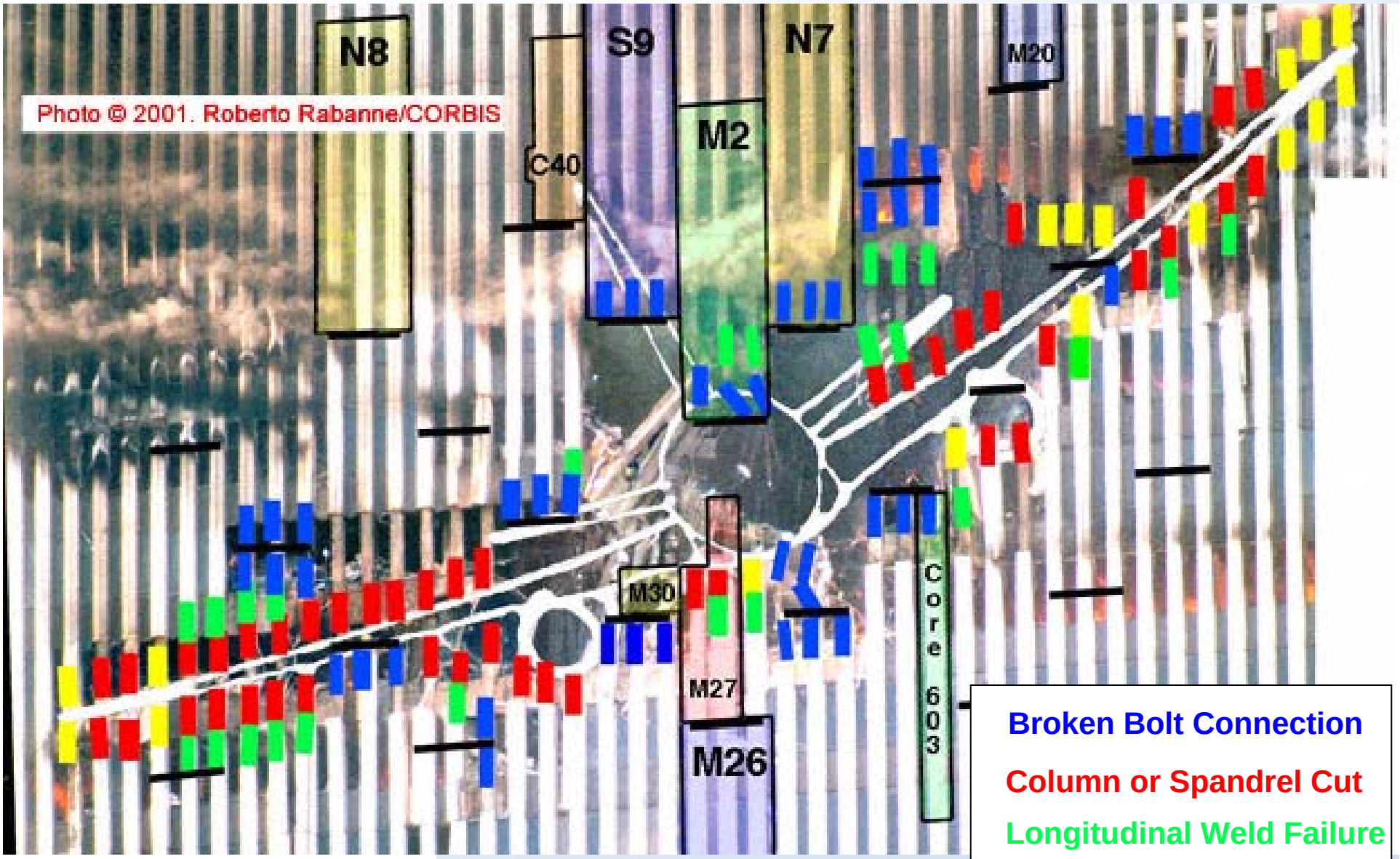
Severe Floor Damage

- Fireproofing and partitions
- Floor system structural damage
- Floor system removed

Column Damage

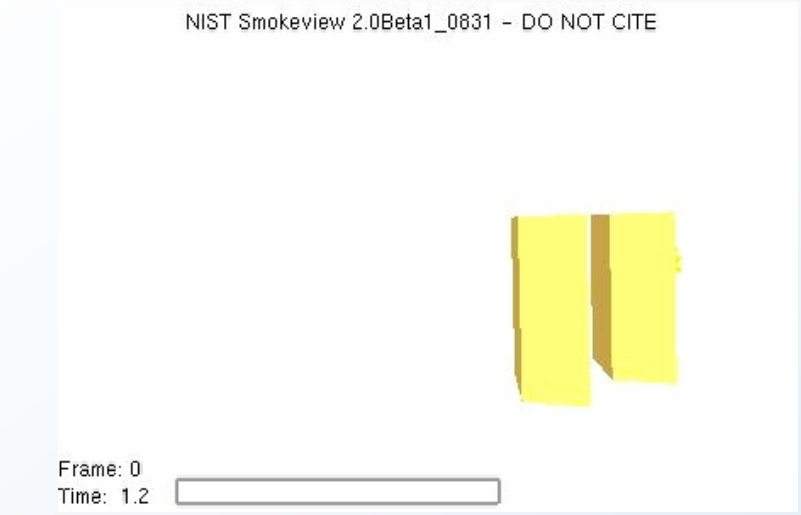
- Severed
- Heavy Damage
- Moderate Damage
- Light Damage

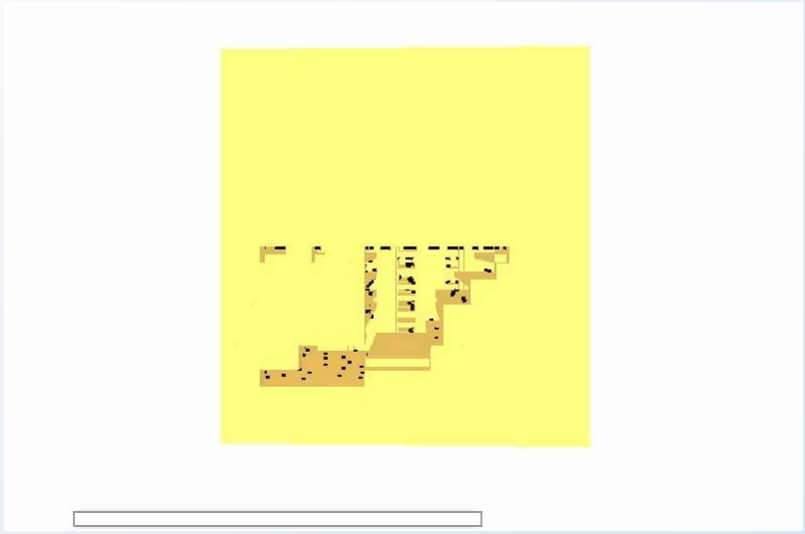


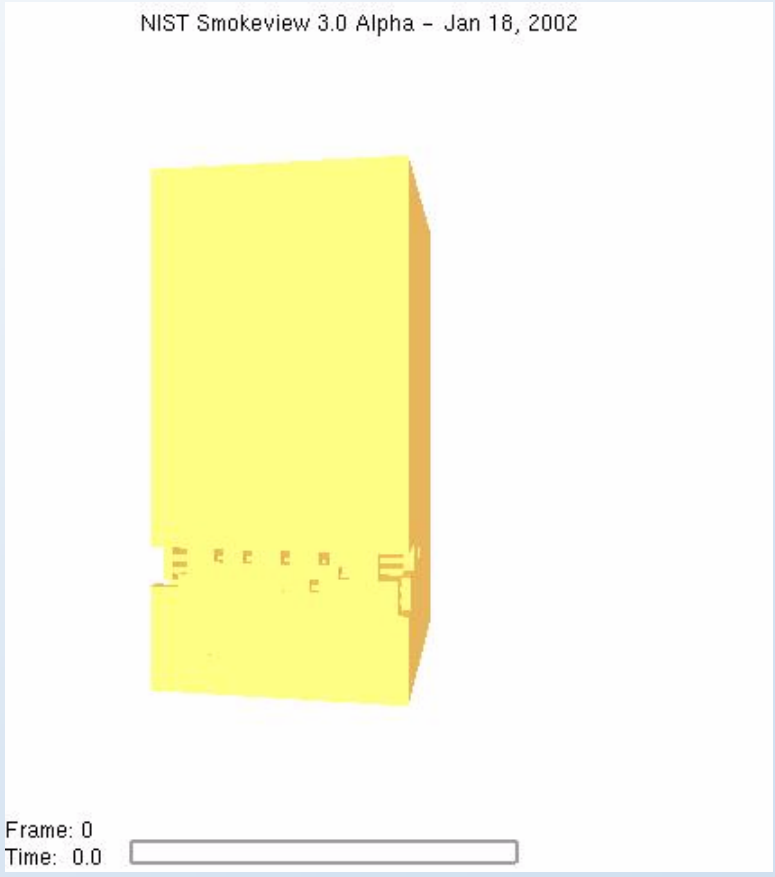


Enhancements added by NIST.

Initial Fire and Smoke Simulations: Fall 2001







Relative Roles of Aircraft Impact and Fires

- **Fires played a major role in further reducing the structural capacity of the buildings, initiating collapse. While aircraft impact damage did not, by itself, initiate building collapse, it contributed greatly to the subsequent fires and the thermal response of the structures** by:
  - Compromising the sprinkler and water supply systems;
  - Dispersing jet fuel and igniting building contents over large areas;
  - Creating large accumulations of combustible matter containing aircraft and building contents;
  - Increasing air supply into the damaged buildings, allowing fires to spread rapidly on multiple floors;
  - Damaging and dislodging fireproofing from structural components; and
  - Damaging ceilings that enabled "unabated" heat transport over the floor-to-ceiling partition walls and to structural components.
- **The jet fuel, which ignited the fires, was mostly consumed within the first few minutes after impact. The fires that burned for almost the entire time that the buildings remained standing were due mainly to burning building contents and, to a lesser extent, aircraft contents, not jet fuel.**
- **Typical office furnishings were able to sustain intense fires for at least an hour on a given WTC floor. The typical floor had on average about 4 psf of combustible materials on floors.** Mass of aircraft solid combustibles was significant in the immediate impact region of both WTC towers.

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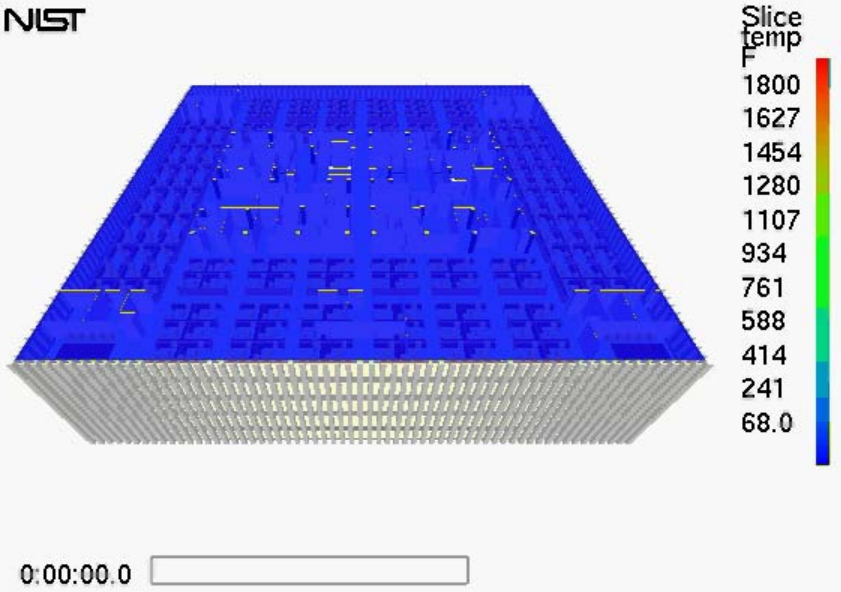
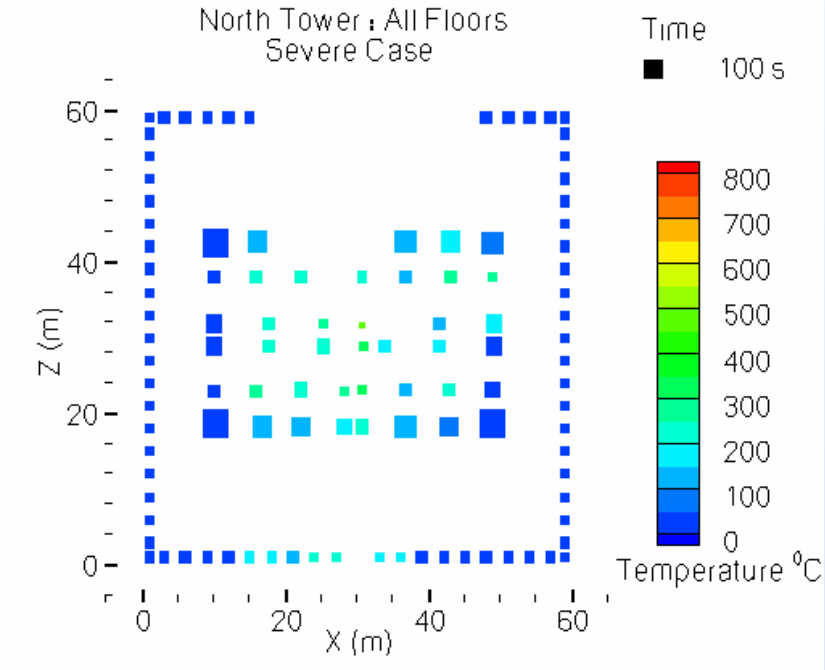
Reconstruction of the WTC Fires

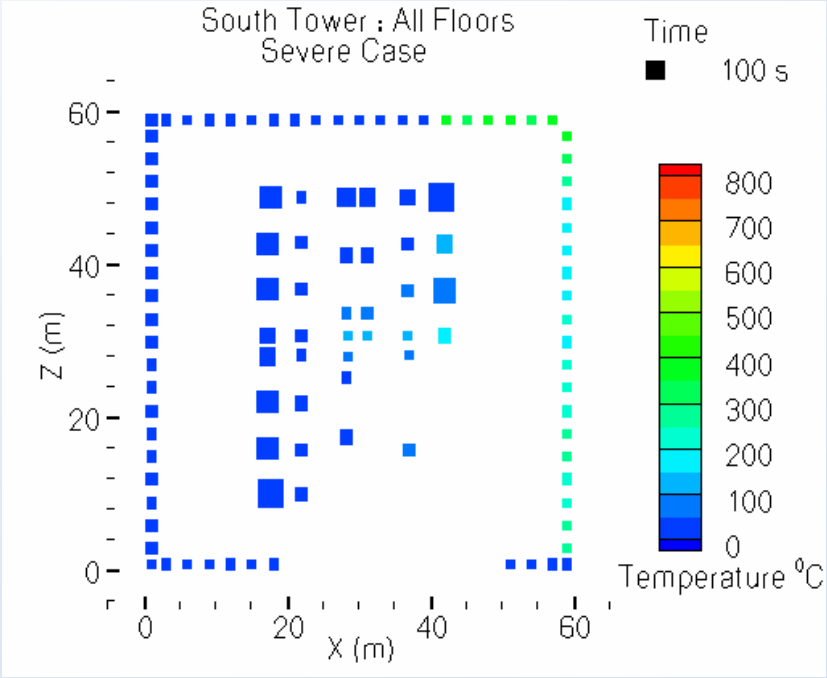


Results of Thermal Analysis (Severe Case)

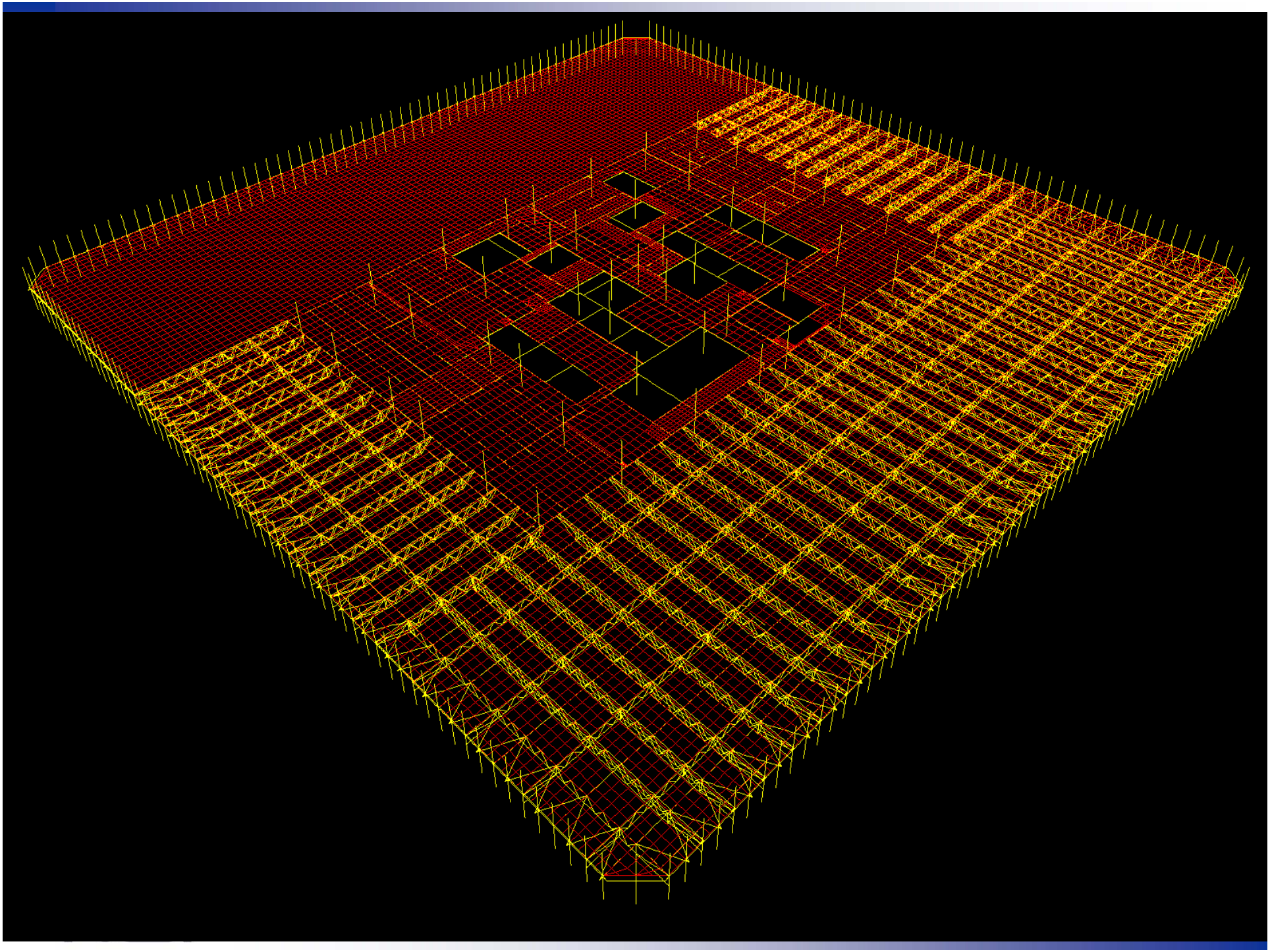
WTC 1

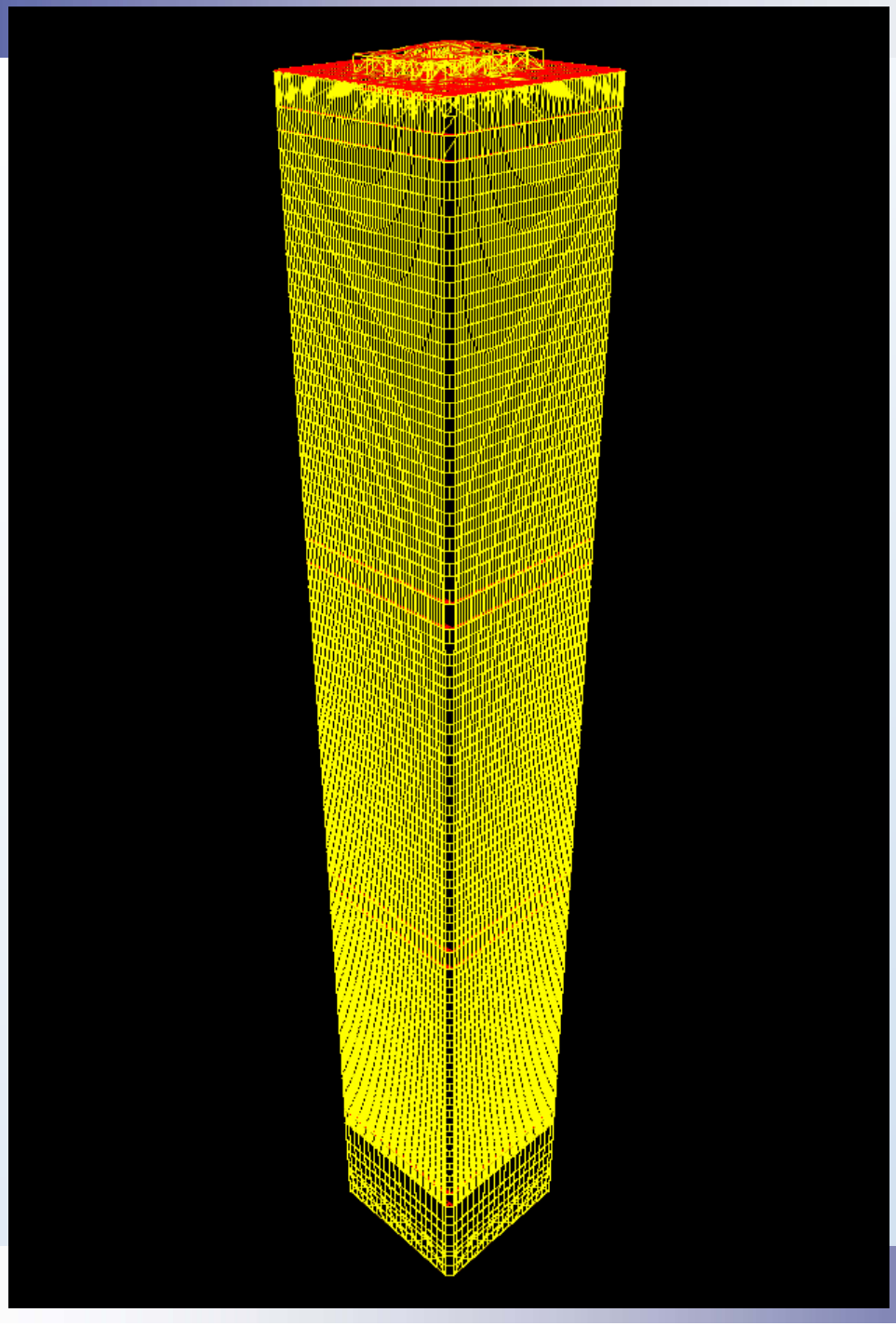


WTC 2



Shows maximum temperature reached by each column.





South Face of WTC1

- Time: 10:22 AM
- Measurements of inward bowing (inches)
- **Maximum = 55 inches** (uncertainty ~ +/- 6 inches)

- Floor locations approximate
- Blue tinted region digitally enhanced

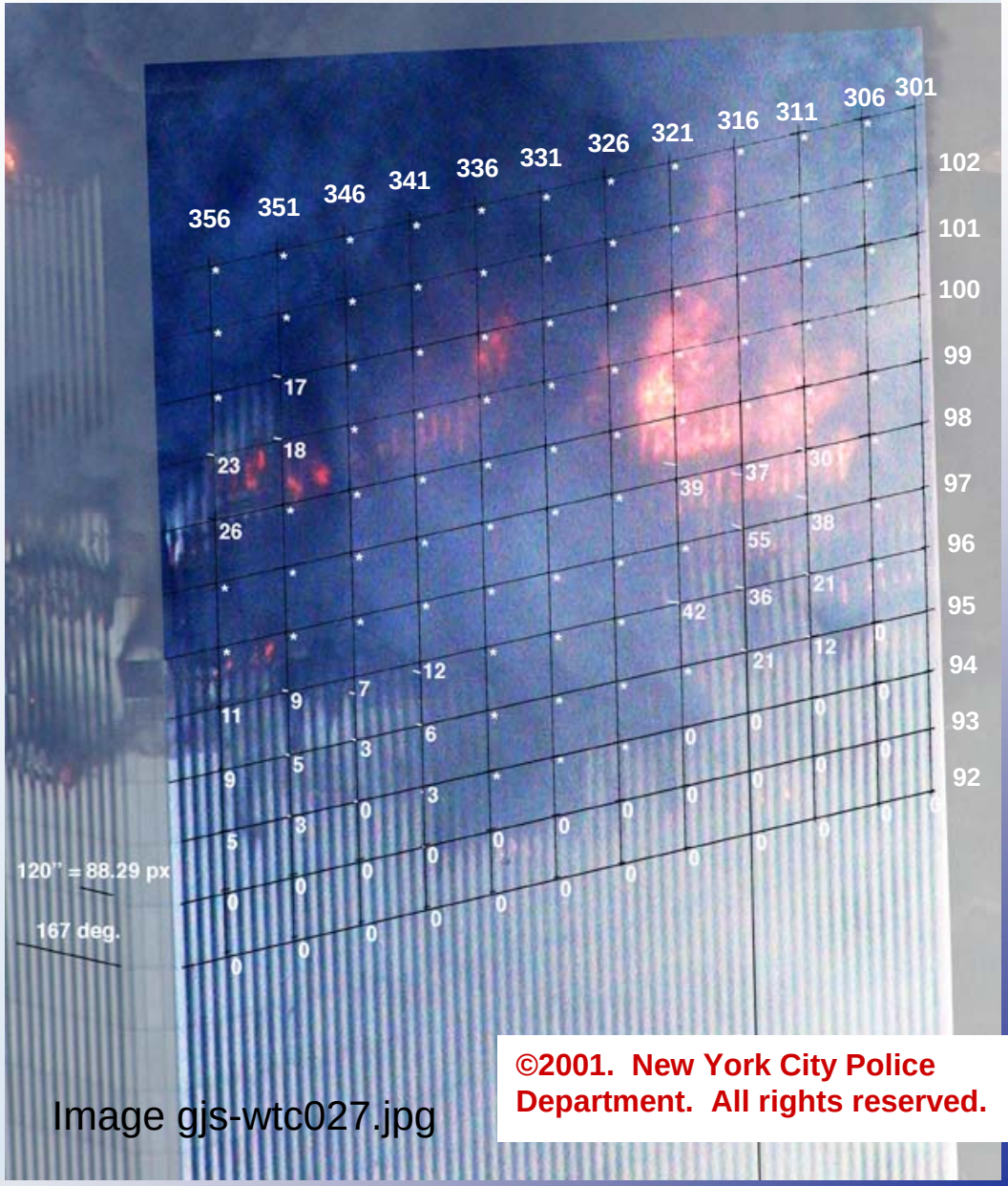
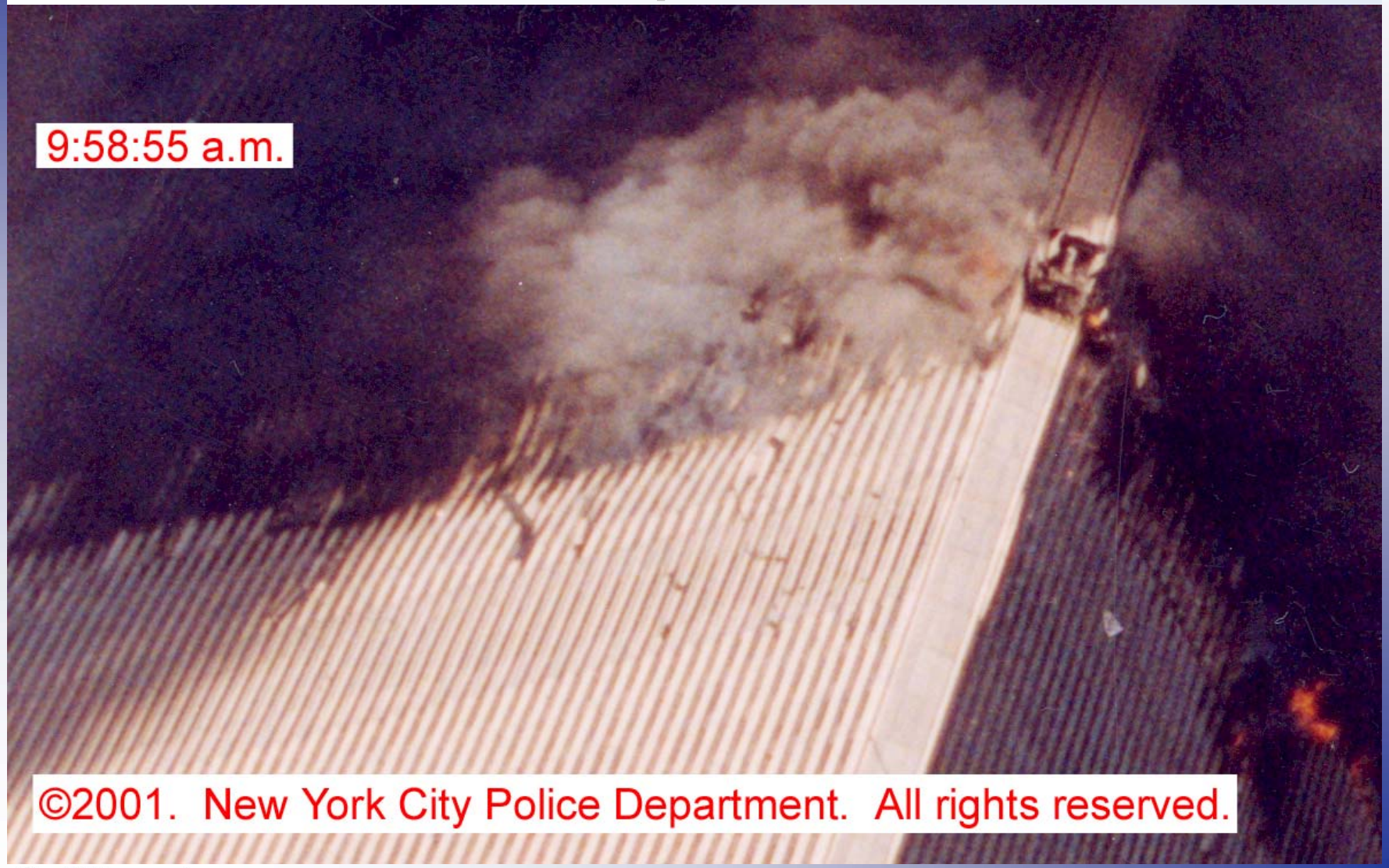


Image gjs-wtc027.jpg

Inward Bowing of Perimeter Columns Some Minutes Prior to Collapse: WTC 2 East Face



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Tilting of Building Sections

WTC 1 tilted to the south; WTC 2 tilted to the east and south and twisted in a counterclockwise motion

Initiation of global collapse was first observed by the tilting of building sections above the impact regions of both WTC towers.

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WTC 1: First Responder Communications

- 10:06 am — NYPD aviation unit advises everybody to evacuate the area in the vicinity of Battery Park City and states that about 15 floors from the top it is totally glowing red on the inside and collapse was inevitable.

  NYPD officer advises that it is isn't going to take much longer before the North tower comes down and to pull emergency vehicles back from the building.

- 10:21 am — NYPD aviation unit first reports that the top of the tower might be leaning, then confirms that it is buckling and leaning to the South.

  NYPD aviation unit reports that the North tower is leaning to the Southwest and appears to be buckling in the Southwest corner.

  NYPD officer advises that all personnel close to the building pull back three blocks in every direction.

- 10:28 am — NYPD aviation unit reports that the roof is going to come down very shortly.

  NYPD officer reports that the tower is collapsing.

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Collection and Analysis of Photographic and Video Images

- Visual database contains:
  - Well in excess of 7,000 photographs taken by more than 185 photographers
  - 150 hours of videotape from major media outlets and more than 20 individuals
- From the analysis of the visual images to date, NIST has identified significant events for WTC 1 and 2 related to aircraft impact, fire development, and building damage
- **NIST has developed detailed mappings for the fire, smoke, and the condition of windows at several specific times for each WTC tower; work is nearing completion for WTC 7**

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Evacuation and Emergency Response

Based on interviews of 1,034 WTC surviving occupants and 116 first responders.

- **It is estimated that 17,400 occupants (± 1,200) were present in the WTC towers on the morning of September 11, 2001.** The initial population of each tower was similar: 8,900 (± 750) in WTC 1 and 8,500 (± 900) in WTC 2. Of those present on September 11, 2001, 16 percent were also present during the 1993 bombing.
  - **About 6 percent of the surviving occupants reported a pre-existing limitation to their mobility.** These limitations included obesity, heart condition, needing assistance to walk, pregnancy, asthma, being elderly, chronic condition, recent surgery or injury, and other.
  - **About 7 percent of the surviving occupants reported having special knowledge about the building.** These included fire safety staff, floor wardens, searchers, building maintenance, and security staff. Searchers assist the floor wardens in facilitating evacuation.
- Approximately **87 percent of the WTC tower occupants, including more than 99 percent of those below the floors of impact, were able to evacuate successfully**.
- Rough estimates indicate that about **20 percent or more of the 2,567 building occupants and first responders who were in the WTC towers and lost their lives may have been alive in the buildings just prior to their collapse**. This estimate includes 118 occupants below the floors of impact who died but not the large but unknown number of occupants above the floors of impact who may have been alive prior to collapse.

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Evacuation Rates in the WTC Towers

- **The overall evacuation rate in WTC 2 (108 survivors per min) was about 50 percent faster than that in WTC 1 (73 survivors per min).** Overall, about 7,900 survivors evacuated WTC 2 in 73 min (i.e., from the instant the WTC 1 was struck by aircraft until WTC 2 collapsed); while about 7,500 survivors evacuated WTC 1 in 103 min.

- **After the first airplane struck WTC 1 and before the second airplane struck WTC 2**, the survivors in WTC 2 were twice as likely as those in WTC 1 to have already exited the building (41 percent versus 21 percent). **The rate of evacuation completion in WTC 2 was twice the rate in WTC 1** during that same period.

  - Approximately 75 percent of WTC 2 occupants above the 78th floor at 8:46 am successfully descended below the 78th floor prior to the aircraft strike at 9:03 am.

  - **Functioning elevators allowed many (roughly 3,000) survivors to self-evacuate WTC 2 during the 16 minutes prior to aircraft impact.** All but one of the 99 elevators in WTC 1 were not functioning, and survivors could only use the stairways.

- Soon after WTC 2 was struck by the airplane until about 20 min before each building collapsed, the survivors in WTC 2 and WTC 1 exited at about the same rate (the prior evacuation rate of WTC 1).

- During the last 20 min before each building collapsed, the evacuation rate in both buildings slowed to about one-fifth the immediately prior evacuation rate. This suggests that **for those seeking and able to reach and use undamaged exits and stairways, the egress capacity (number and width of exits and stairways) was adequate to accommodate survivors**.

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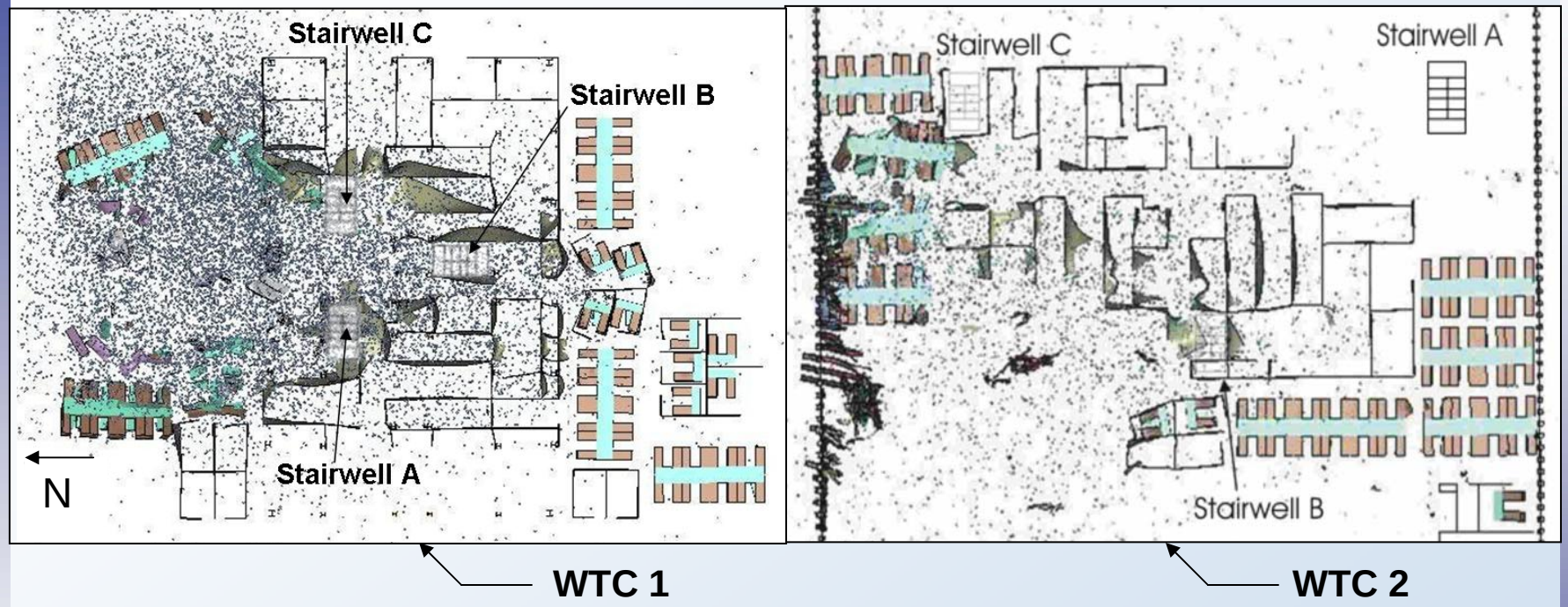
Condition of Stairwells



- The stairwells, with partition wall enclosures that provided a 2 h fire-rating but little structural integrity, were damaged in the region of the aircraft impacted floors.
- **One of the stairwells in WTC 2 (Stairwell A on the Northwest side) was passable in the region of aircraft impact for some period of time after WTC 2 was attacked.**
- All three stairwells in WTC 1 and the two other stairwells in WTC 2 were rendered impassable in the region of aircraft impact.

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Evacuation Rates in the WTC Towers (2)

- Even though a percentage of evacuees reported that they perceived **counterflow (firefighter ingress)** to be problem, it **was found not to be a significant factor in the total evacuation time of occupants in WTC 1 when compared to other factors,** including evacuation initiation delay, evacuation interruption, and encountering obstacles in the evacuation path (environmental cues) such as smoke, water, or debris.

- Based on use of existing egress models and actual evacuation time on September 11, 2001, it is estimated that **a full capacity evacuation of each WTC tower with 25,000 people—three times the number present on September 11, 2001—would have required about 4 hours**. To achieve a significantly faster total evacuation at full capacity would have required increases in egress capacity (number and width of exits and stairways).

- **The average surviving occupants moved slower down stairs and through stairwell exits than previously reported for non-emergency evacuations.**

  - In WTC 1, the average surviving occupant spent 48 seconds per floor descending the stairwell. This translates to approximately 0.2 m/s (0.65 ft/s), which is about 50% of the slowest speed measurement presented in the SFPE Handbook of Fire Protection Engineering for non-emergency evacuations.

  - In WTC 1, each stairwell door exited approximately 37 people per minute, averaged over 100 minutes, which is comparable to the slowest measurement presented in the SFPE Handbook of Fire Protection Engineering for non-emergency evacuations.

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Occupant Preparedness

- **Two-thirds of surviving occupants reported having participated in a fire drill in the 12 months prior to September 11, 2001, while 17 percent reported that they received no training during that same period.**
  - Of those participating in fire drills, **93 percent were instructed about the location of the nearest stairwell.**
  - Overall, **slightly over half of the survivors, however, had never used a stairwell at the WTC prior to September 11, 2001** (NYC Local Law 5 prohibits **requiring** occupants to practice stairwell evacuation.)
- **Occupants were often unprepared for the physical challenge of full building evacuation.** Numerous occupants required one or more periods of rest during stairwell descent or turned to elevators after finding the stairwells strenuous.
- **Occupants were often unprepared to encounter transfer hallways during the stairwell descent.** Groups of evacuees occasionally hesitated or debated a course of action upon encountering a transfer hallway.
- **Mobility challenged occupants were not universally identified or prepared for full building evacuation.** One occupant, for example, reported being 'left' on their floor by colleagues, called authorities for assistance, and was eventually assisted by strangers (occupants).

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Emergency Responder Operations

Situational Awareness:

- Emergency responders working outside of the WTC buildings that could view building conditions and communicate over radios had adequate situational awareness.

- Situational awareness for personnel who observed the building damage and fires from outside the buildings before entering experienced difficulty maintaining their awareness after entering the buildings.

- Emergency responders working inside of the WTC buildings, who could not see what was happening outside and had poor radio communications, had poor situational awareness.

- Emergency responders working inside of the WTC buildings, who could not see what was happening outside and had good radio communications, had better situational awareness than those with poor radio communications.

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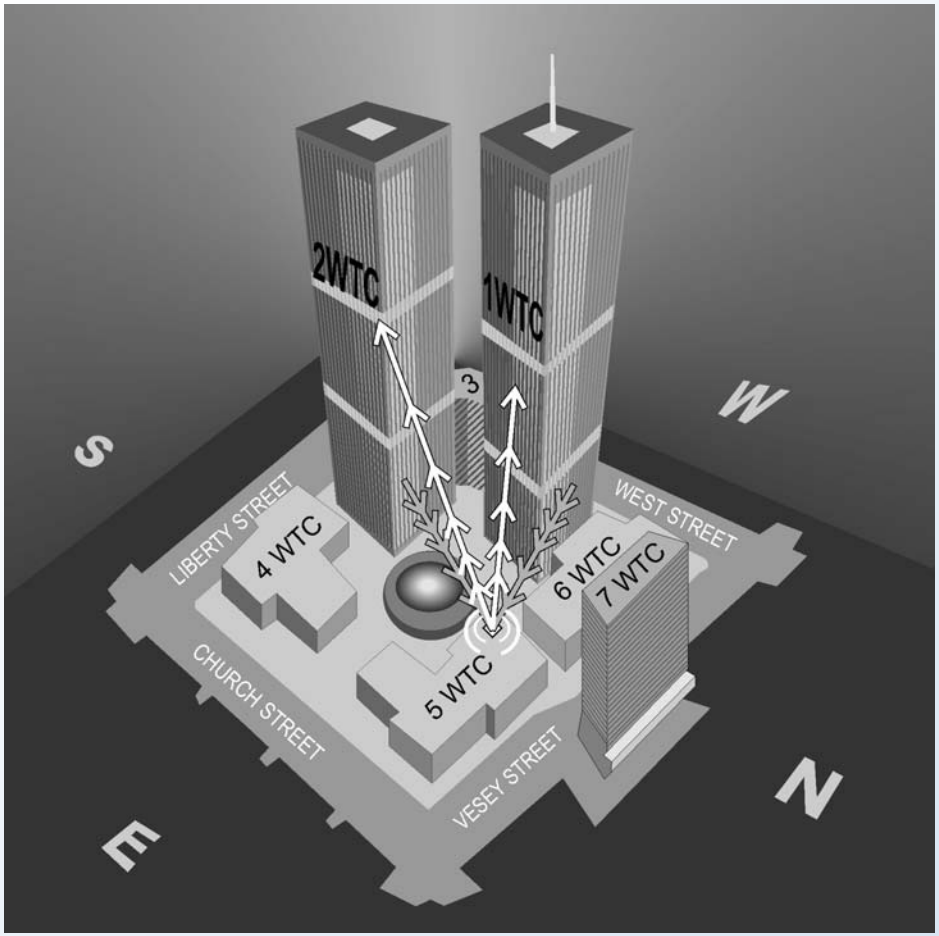
Radio Communications in High-Rise Buildings



Schematic of WTC Radio Repeater System

- Challenging radio-frequency propagation environment: steel and reinforced concrete buildings.
- Large scale operations.
  - Number of first responders.
  - Communications hierarchy and protocols.
  - Surge in traffic; doubling.
- Interoperability of radio communication technologies among different first responder organizations.
- Identification, location, tracking first responders.

NIST

WTC High-Rise Radio Repeater System

- **Analysis of the FDNY City-wide, high-rise, channel 7 (PAPD channel 30) repeater recording indicates that the World Trade Center high-rise repeater was operating.**

- At approximately 9:05 a.m. the repeater's recording system recorded the WTC 1 Lobby Command Post attempts to check repeater operations. Handset and handie-talkie radio communications were recorded.

- It is possible that one or both of the following conditions complicated the radio check that took place at the WTC 1 Lobby Command Post:
  - The radio repeater handset earpiece was broken.
  - The radio repeater handset volume was not turned up.

- **It is unlikely that the repeater's antenna was broken or misdirected by debris since radio signals were received during the radio check from inside WTC 1 and the communications that followed from inside WTC 2. Even if the repeater was functioning, it is possible the quality of communications was inadequate.**

- The repeater's system recorded radio communications that took place between several different firefighters and several different FDNY officers as they worked inside WTC 2.

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Emergency Responders & High-Rise Buildings

- First responding FDNY units took from 4 to 10 minutes to get to the WTC complex. They then got their equipment and received assignments, another 3 to 5 minutes. Time to begin operations 7 to 15 minutes.

- Of the 27 emergency responders interviewed that were inside WTC 1, maximum floor height achieved before WTC 2 collapsed, a time period of 1 hour 13 minutes.

  1 – A police officer carrying no extra equipment and in a patrolman's uniform climbed to the 44th floor.

  8 – Emergency responders (FDNY, PAPD, NYPD) climbed to the 30's Two FDNY took an elevator to the 16th floor.

  16 – Emergency responders (mostly FDNY) climbed to the 20's.

  2 – Emergency responders (NYPD) climbed to the teens.

- **Estimated climbing rate based on a 60 minute climbing period to their maximum height: 1.4 to 2 minutes/floor**

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High-Rise Buildings & Emergency Response

Example: Fire department response to a 60 story high-rise building, occupants trapped above fires on the 58th floor and no operating elevators.

Firefighters carrying equipment and wearing PPE ~ 125 minutes
Firefighters carrying no equipment and not wearing PPE ~ 90 minutes

Firefighters carrying equipment and wearing PPE ~ 70 minutes
Firefighters carrying no equipment and not wearing PPE ~ 50 minutes

Firefighters begin to climb 10 minutes
Fire department arrival 4 minutes

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Mobility Impaired Occupants

- As the emergency responders started evacuating WTC 1 after the collapse of WTC 2, they found mobility impaired occupants still in the staircases going down.

- Ambulatory mobility impaired occupants typically walked down the stairs with one hand on each hand rail and took one step at a time going down. In addition, they were typically accompanied by one person, another occupant or an emergency responder. This blocked others behind them from moving more rapidly down the stairs.

- **FDNY and PAPD personnel found 40 to 60 mobility impaired occupants on the 12th floor of WTC 1 as they went down and attempted to clear each floor on their way out.** These impaired individuals had been placed on this floor in an attempt to clear the stairways.

- **Emergency responders were assisting approximately 20 of these mobility impaired people down the staircase just prior to the collapse of WTC 1.** It is unknown how many fatalities occurred with this group.

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Building and Fire Codes in the United States

- In the United States, state and local governments are responsible for promulgating and enforcing building and fire regulations.
- With some exceptions, the state and local regulations are based on national model building and fire codes developed by private sector organizations.
- The model codes, in turn, reference voluntary consensus standards developed by a large number of private sector standards development organizations (SDOs) accredited by the American National Standards Institute (ANSI).
- NIST does not set building codes and standards, but provides technical support to the private sector and other government agencies in the development of U.S. building and fire practices, standards, and codes.
- NIST recommendations are given serious consideration by private sector organizations that develop national standards and model codes – which provide minimum requirements for public welfare and safety.

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Approach to Recommendations

- In accordance with Section 8 of the enabling statute (15 USC 7301 et seq), the National Construction Safety Team's final report is required to include recommendations that address:
  - Specific improvements to building standards, codes, and practices
  - Changes to, or the establishment of, evacuation and emergency response procedures
  - Research and other appropriate actions needed to help prevent future building failures

- NIST intends to issue draft recommendations for public comment that identify specific improvements in the way buildings are designed, constructed, maintained, and used.

- NIST believes that its recommendations will be both realistic and achievable within a reasonable period of time and that their implementation would make buildings, occupants, and first responders safer in future emergencies.

- NIST will strongly urge that immediate and serious consideration be given to its recommendations by the building and fire safety communities—especially designers, owners, developers, fire safety professionals, and emergency responders.

- NIST is making a top priority to work vigorously with these communities to assure that there is complete understanding of the recommendations and their technical basis and to provide needed technical assistance. This includes a web-based system that will be available to the public so that progress in implementing NIST's recommendations can be tracked.

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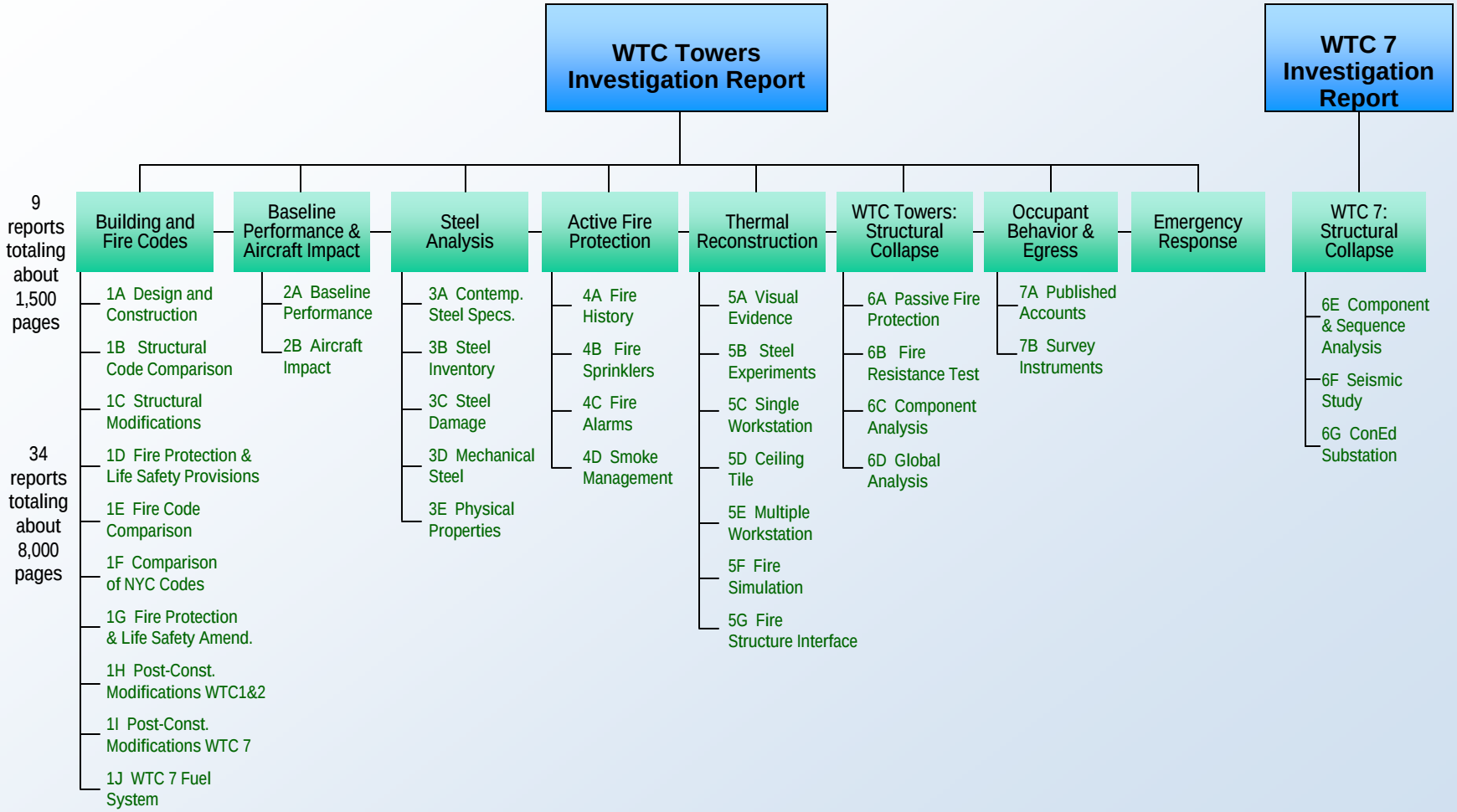
WTC Investigation Reports



43 reports for WTC Towers; 5 reports for WTC 7

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Challenges Addressed

- Strong, conflicting public perspectives
- Competing collapse hypotheses
- Need for significant advances in state-of-the-art
- Need for developing NCST rules, human subjects protocols
- Coordination with 9/11 Commission and local authorities
- Blending “investigation” needs with “research” culture
- Leading and managing an extended investigation team of 236 people (85 staff from 3 NIST Laboratories; 124 contractors and technical experts; 27 secretariat/institutional support staff)

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Examples of Extensive Media Coverage…

- **Newspapers**
  - ***The New York Times***
  - ***The Washington Post***
  - ***The Wall Street Journal***
  - ***The International Herald Tribune***
  - ***The Guardian (UK)***
  - New York City newspapers
  - Major U.S. newspapers
  - International newspapers
- **Magazines and Books**
  - ***The 9/11 Commission Report***
  - ***City in the Sky*** (Glanz & Lipton)
  - ***102 Minutes*** (Dwyer & Flynn)
  - ***Engineering News-Record***
  - ***Popular Mechanics***
- **Wire Services**
  - ***Associated Press***
  - ***Reuters***
  - ***United Press International***
- **TV and Radio Networks**
  - ***CBS Evening News***
  - ***CNN International***
  - ***WABC***
  - ***WNBC***
  - ***Fox News***
  - ***NY1***
  - ***C-Span***
  - ***NPR***
  - ***WNYC*** (NY Public Radio)
  - ***Metro Radio Network***

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Background Slides

The Extended WTC Investigation Team

• WTC Investigation Team	14
• Other NIST Technical Staff	71
• Secretariat/Institutional Support	27
• Contractor Staff	112
• Experts (Contract/Employee)	12
	=====
Total	**236**

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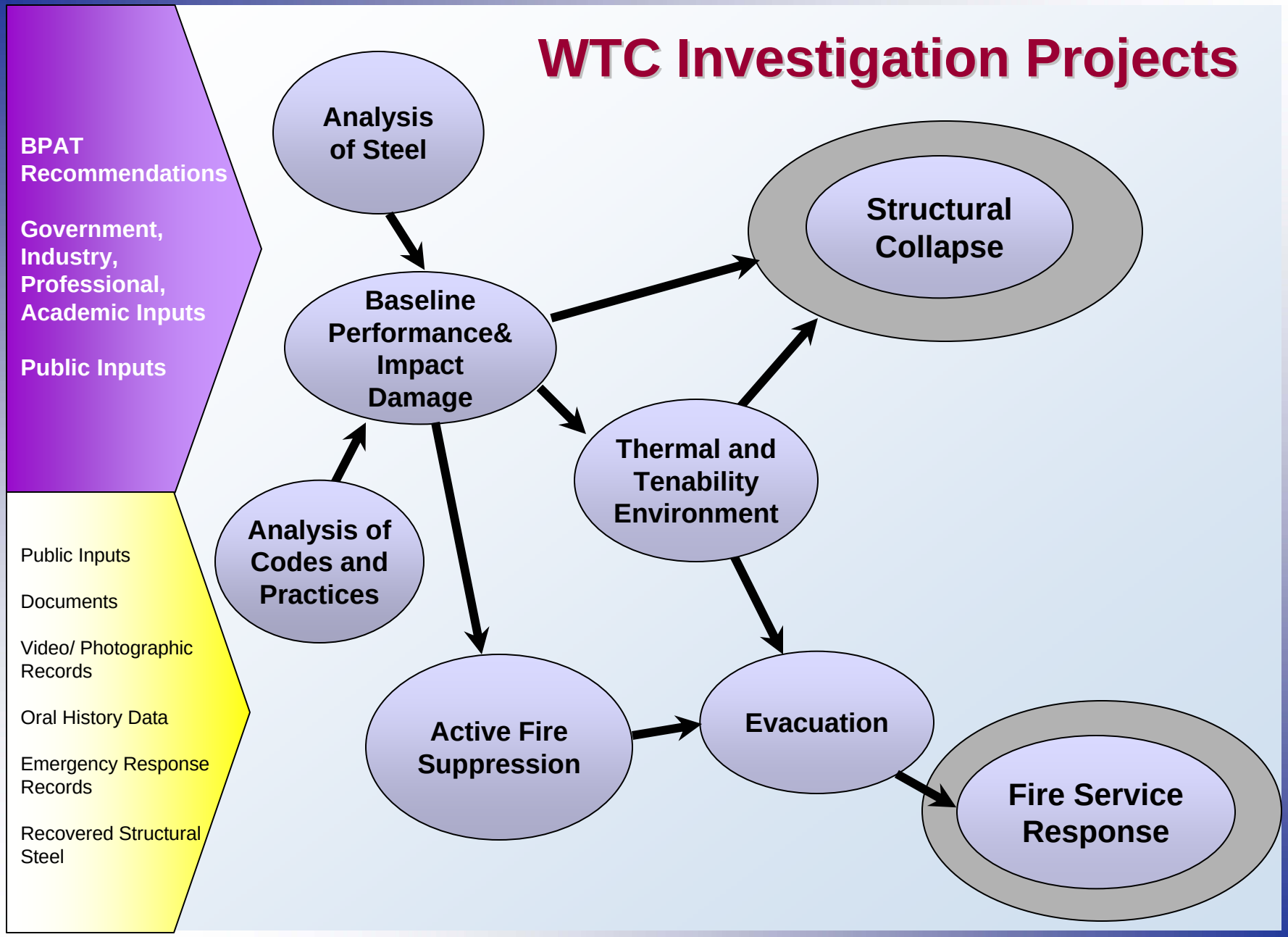
WTC Investigation Projects



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Context of Findings

- Buildings are not specifically designed to withstand the impact of fuel-laden commercial airliners. While documents from the Port Authority of New York and New Jersey (PANYNJ) indicate that the impact of a Boeing 707 flying at 600 mph, possibly crashing into the 80th floor, was analyzed during the design of the WTC towers in February/March 1964, the effect of the subsequent fires was not considered. Building codes do not require building designs to consider aircraft impact.

- Buildings are not designed for fire protection and evacuation under the magnitude and scale of conditions similar to those caused by the terrorist attacks of September 11, 2001.

- The load conditions induced by aircraft impacts and the extensive fires on September 11, 2001, which triggered the collapse of the WTC towers, fall outside the norm of design loads considered in building codes.

- Prior evacuation and emergency response experience in major events did not include the total collapse of tall buildings such as the WTC Towers and WTC 7 that were occupied and in everyday use; instead, that experience suggests that major tall building fires result in burnout conditions, not overall building collapse.

- The PANYNJ was created as an interstate entity, under a clause of the U.S. Constitution permitting compacts between states, and is not bound by the building and fire codes of any local, state, or federal jurisdiction. The PANYNJ's longstanding stated policy is to meet and, where appropriate, exceed requirements of local building and fire codes.

WTC Investigation Status

- Investigation nearing completion; drew talent from NIST, outside experts, and contractors; $16 million investigation; $5.5 million awarded in contracts.
- Two public updates issued (December 2002, December 2003); two technical progress reports issued (May 2003, June 2004). Full text available on Web site http://wtc.nist.gov.
- Three major public meetings held:
  - June 24, 2002 (NYC) to present draft WTC investigation plan and solicit comments on the plan.
  - February 12, 2004 (NYC) to solicit comments on (1) technical aspects of investigation, (2) additional information that NIST might consider, (3) areas to be considered for recommendations.
  - August 24, 2004 (Chicago) to observe fire resistance test of WTC floor system at Underwriters Laboratories
- Six media/public briefings on investigation progress, extensive briefings at six meetings of the National Construction Safety Team Advisory Committee, and one meeting to solicit public inputs for first-person interviews of occupants and first responders. Numerous technical briefings to the professional community.
- Current findings may be revised and additional findings will be presented in final report.
- **NIST is not making any recommendations at this time; all recommendations will be made in the final report.**

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Schedule for Completion of Investigation

- Major focus is on writing the Investigation reports; technical work is nearly complete.
- The time required to write and review the comprehensive set of draft documents that constitute final WTC investigation findings and recommendations is driving the release date of the report.
- The NIST reports include the overall investigation report for the WTC towers, 8 project separate project reports, and 34 supporting technical reports, totaling some 10,000 pages. This enormous task has taken NIST longer to accomplish than originally anticipated.
- NIST is committed to putting accuracy, quality, and completeness ahead of schedule, taking whatever time is required to do the job right.
- NIST plans to release a draft of the final report for public comment in May 2005; public comment period of about 6 weeks after release of the draft reports; NIST plans to release final Investigation report in July 2005.
- WTC 7 report will be issued as a supplement to the main report: draft planned for October 2005; final for December 2005.
  - Decoupling of WTC 7 report necessary to accommodate overlapping staffing demands for work on WTC towers.
  - This change affects mainly the collapse analysis; other WTC 7 work will be reported with the other Investigation reports.
- WTC Conference: Putting Recommendations into Practice, June 2005; opportunity for public comment on draft report.

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National Construction Safety Team Act
PL 107-231

- ***Congress directs NIST to investigate building failures that have resulted in "substantial loss of life or that posed significant potential for substantial loss of life."***
  - **NIST investigations are to assess building performance and emergency response and evacuation procedures.**
  - Building failures include those caused by extreme natural events (earthquakes, hurricanes, tornadoes, floods, etc.), building or community-scale fires, failures during construction or in active use, acts of terrorism, Presidential disaster declarations, activations of National Response Plan.
- ***Modeled by Congress after the National Transportation Safety Board; provides NIST with similar authorities.***
- ***NIST is carrying out the World Trade Center investigation and the Rhode Island Nightclub Fire investigation under the authority of the Act.***
- ***NIST is required to establish and deploy an investigation team within 48 hours of building failures to the maximum extent possible.***

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Earthquakes

- San Fernando, CA (1971)
- Mexico City, Mexico (1985)
- Loma Prieta, CA (1989)
- Northridge, CA (1994)
- Kobe, Japan (1995)
- Kocaeli, Turkey (1999)

Hurricanes

- Camille, MS/LA (1969)
- Alicia, Galveston, TX (1983)
- Hugo, SC (1989)
- Andrew, FL (1992)
- Hurricane Mitch and Georges, LAC (1998)

Construction/Building

- Skyline Plaza Apartments, Bailey's Crossroads, VA (1973)
- Willow Island Cooling Tower, WV (1978)
- Kansas City Hyatt Regency, Kansas City, MO (1981)
- Riley Road Interchange, East Chicago, IN (1982)
- Harbor Cay Condominium, Cocoa Beach, FL (1981)
- L'Ambiance Plaza, Hartford, CT (1987)
- Ashland Oil Tank Collapse, Floreffe, PA (1988)
- U.S. Embassy, Moscow, USSR (1987)
- Murrah Federal Building, Oklahoma City, OK (1995)

Tornadoes

- Jarrell, TX (1997)
- Spencer, SD (1998)
- Oklahoma City, OK (1999)

Fires

- DuPont Plaza Hotel, San Juan, PR (1986)
- First Interstate Bank Building, Los Angeles, CA (1988)
- Loma Prieta Earthquake, CA (1989)
- Hillhaven Nursing Home (1989)
- Pulaski Building, Washington, D.C. (1990)
- Happyland Social Club, Bronx, NY (1990)
- Oakland Hills, CA (1991)
- Hokkaido, Japan (1993)
- Watts St, New York City (1994)
- Northridge Earthquake, CA (1994)
- Kobe, Japan (1995)
- Vandaila St, New York City (1998)
- Cherry Road, Washington, DC (1999)
- Keokuk, IA (1999)
- Houston, TX (2000)
- Phoenix, AZ (2001)

Prior NIST Investigations…

Results:

- Probable technical cause
- Lessons learned: successes and failures
- Improvements to standards, codes, and practices, technologies
- Establish future research priorities

Existing Authorities:

- ***NCST Act (2002):*** building failures, evacuation and emergency response procedures
- ***NIST Act (1986):*** structural investigations
- ***NEHRP Reauthorization Act (1990):*** earthquakes
- ***National Post-Storm Data Acquisition Plan:*** wind, storms and floods
- ***National Response Plan:*** structural and fire safety; disaster operations and situation assessment; urban and industrial hazard analysis; mitigation
- ***Fire Prevention and Control Act (1974):*** fire investigations

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Some of WTC Response Plan's Advocates

- American Concrete Institute, Strategic Development Council
- American Society of Civil Engineers, and Civil Engineering Research Foundation
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers
- American Society of Mechanical Engineers
- Associated General Contractors
- Building Owners and Managers Association
- Construction Industry Institute, and the Fully Integrated and Automated Technology (FIATECH)
- Construction Industry Round Table
- International Association of Fire Chiefs
- International Code Council
- National Association of State Fire Marshals
- National Conference of States on Building Codes and Standards
- National Fire Protection Association
- National Institute of Building Sciences and International Alliance for Interoperability--North America
- Skyscraper Safety Campaign
- The Infrastructure Security Partnership

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Data Collection and Sources

- NIST based its review, analysis, modeling, and testing work for the World Trade Center (WTC) Investigation on a solid foundation of technical evidence. This required access to critical data such as building documents, videographic and photographic records, emergency response records, and oral histories, in addition to samples of recovered WTC steel.

- NIST received considerable cooperation and large volumes of information from a variety of organizations and agencies representing the building designers, owners, leaseholders, suppliers, tenants, first responders, contractors, insurers, news media, survivors, and families of victims. The documents and other information relate to the design, construction, operation, inspection, maintenance, repair, alterations, emergency response, and evacuation of the WTC complex.

- NIST received cooperation from The National Commission on Terrorist Attacks Upon the United States (9-11 Commission).

- Local authorities providing information included the Port Authority of New York and New Jersey (PANYNJ) and its consultants and contractors and several New York City agencies, including New York City Fire Department (FDNY); the New York City Police Department (NYPD); the New York City (NYC) Law Department; the NYC Department of Design and Construction (DDC); the NYC Department of Buildings (DoB); and the NYC Office of Emergency Management (OEM).

Data Collection and Sources (2)

- The Occupational Safety and Health Administration provided correspondence sent to it regarding the evacuation experience of WTC occupants on September 11, 2001.
- NIST received information from Silverstein Properties and its consultants and contractors; the group of companies that insured the WTC towers and its technical experts; Nippon Steel; Laclede Steel; U.S. Mineral Products Co. and Isolatek International; Morse Zehntner Associates; W.R. Grace & Co.; Citigroup, formerly Salomon Smith Barney; United Airlines; American Airlines; and Boeing.
- The information from Silverstein and the insurance companies included the large body of technical work completed by both parties as part of the insurance litigation involving the WTC towers, such as reports on the structural collapse, fire spread and severity, and wind tunnel test results for the WTC towers. In addition, technical experts for both parties independently provided extensive briefings to the WTC investigation team and discussed the tenability environment and the evacuation procedures in the buildings.
- NIST received information on floor plans, furnishings, and contents from tenants of all three buildings.
- NIST was unable to gather a small portion of the information since most such evidence was lost when the WTC buildings collapsed. However, the available information was adequate for purposes of the investigation.

Safety of WTC Towers in Aircraft Collision

- Buildings are not normally designed to withstand the impacts of fuel-laden commercial airliners.
- Safety of the WTC towers and their occupants in an aircraft collision was a consideration in the original design.

Available Sources of Information:

- Port Authority (February 1964), three-page white paper, “Salient points with regard to the structural design of The World Trade Center towers,” dated 2-3-64.
- Port Authority (March 1964), three-page document, “period of vibration due to plane crash at 80th floor.”
- Alternative Insurance Works (2001), World Trade Center Property Risk Report, Prepared for Silverstein Properties, Inc.
- *The New Yorker* (11/19/2001), “The Tower Builder” by John Seabrook, Interview with Leslie Robertson.
- FEMA 403 (2002), *World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations.*
- Glanz and Lipton (2003), *City in the Sky – The Rise and the Fall of The – World Trade Center,* Times Books, 2003.

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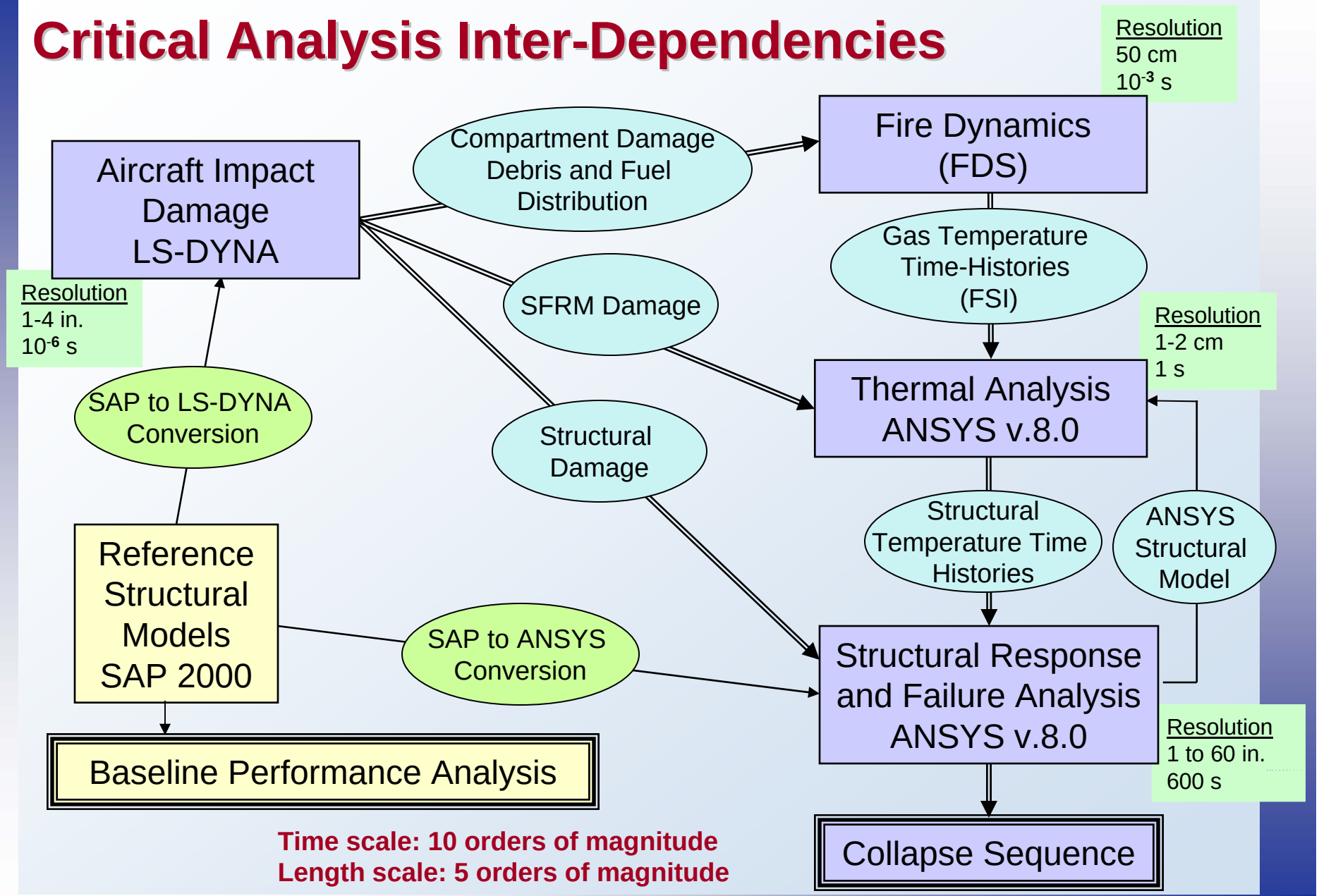
Critical Analysis Inter-Dependencies



Time scale: 10 orders of magnitude
Length scale: 5 orders of magnitude

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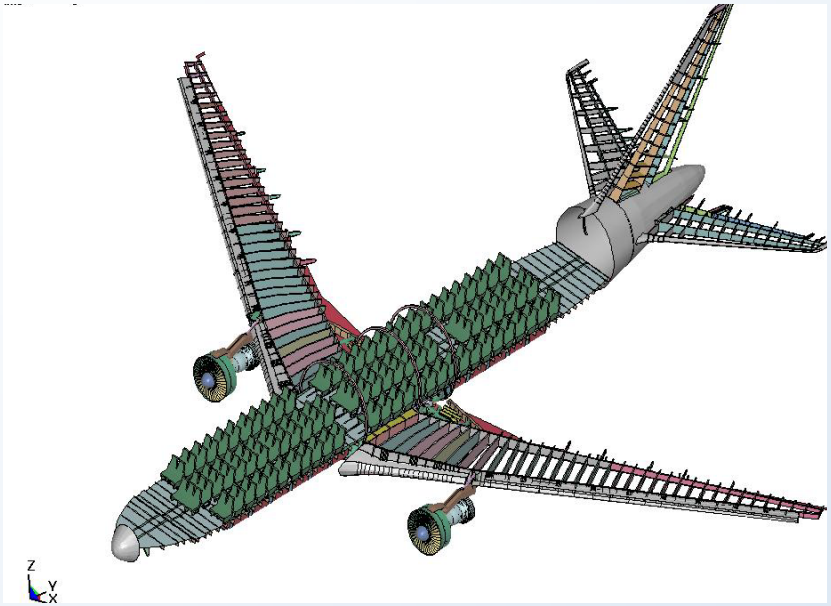
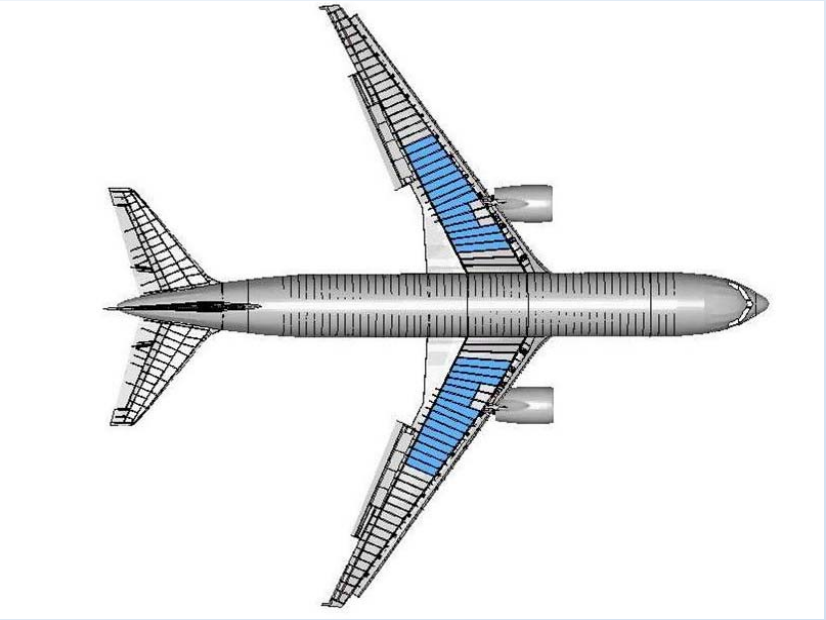
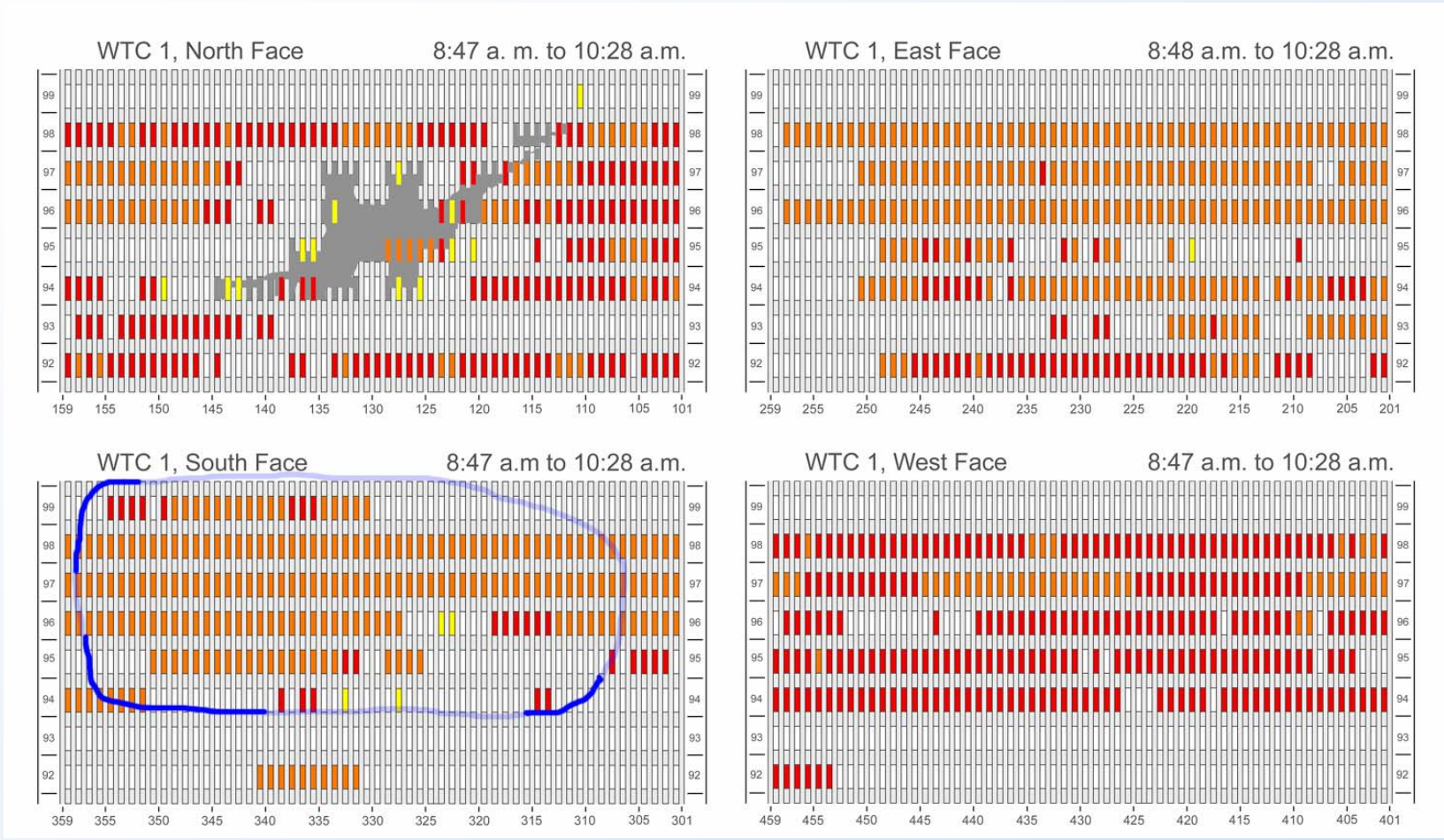
Aircraft Models

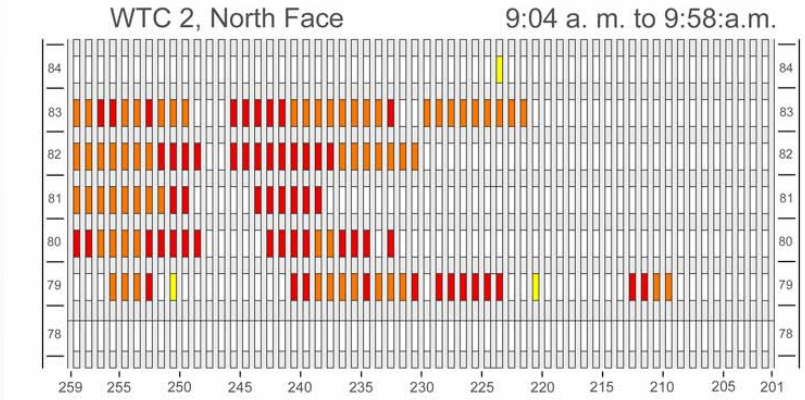


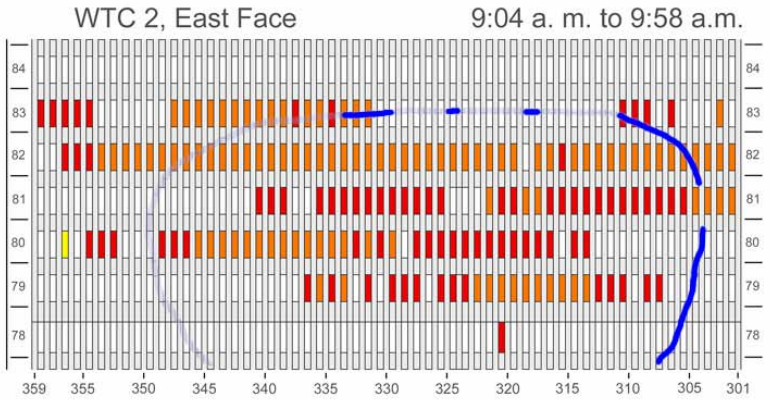


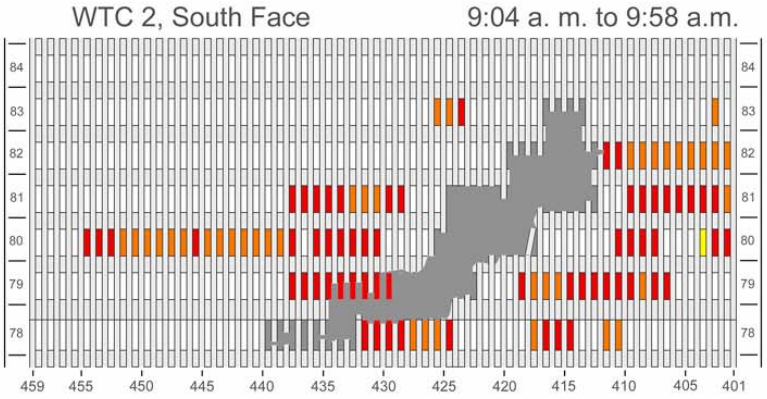
Visual Evidence of Fires in WTC 1

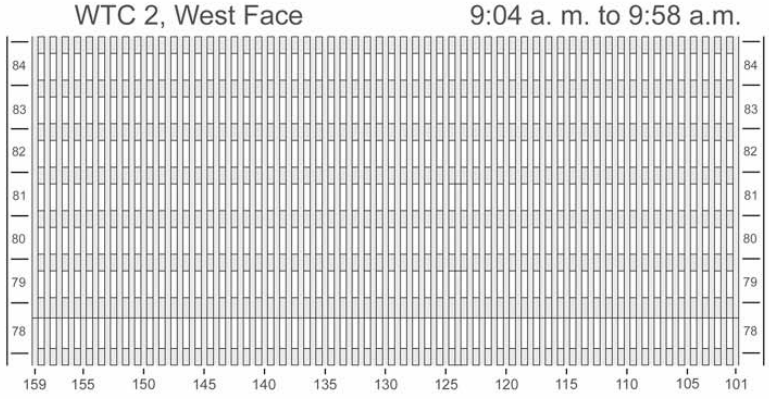


Visual Evidence of Fires in WTC 2

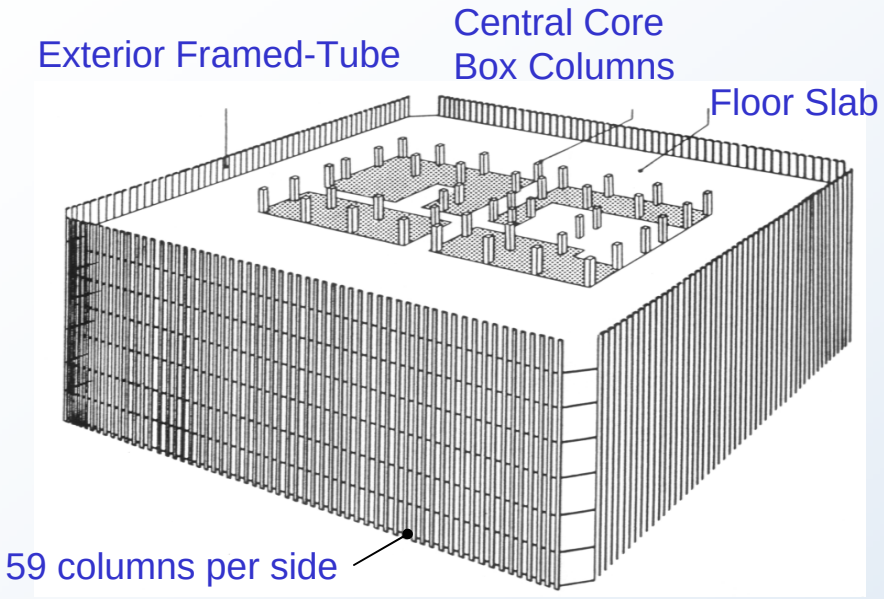


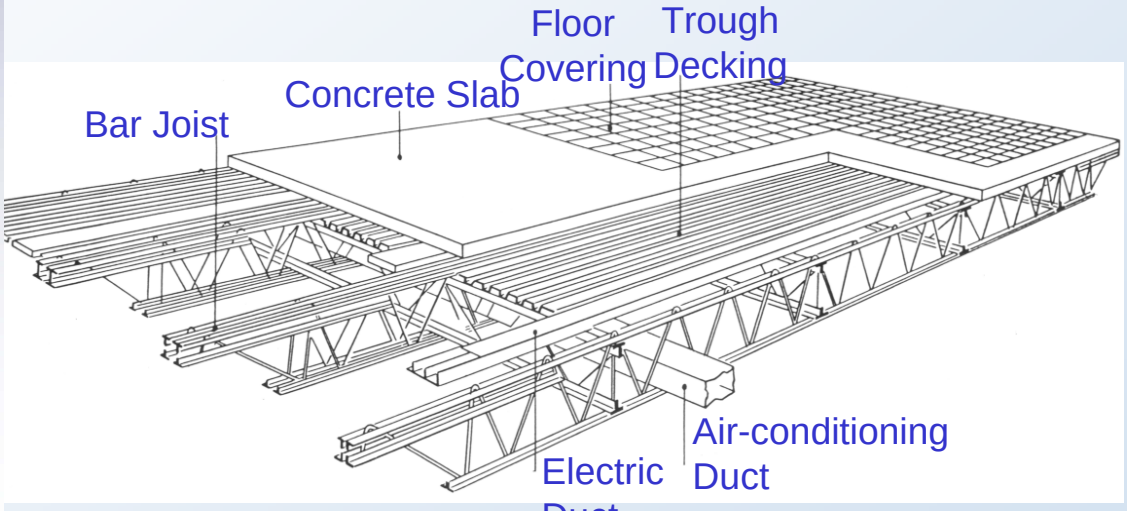






Innovative WTC Tower Structural System





- Innovative structural system when built; incorporated many new and unusual features
- Two features require additional consideration:
  - Composite floor truss system using long span open-web bar joists and spray-applied fireproofing
  - Design for wind loads and control of wind-induced vibrations

NIST

Fire Performance of Composite Floor System

- Fire-protection of a truss-supported floor system with spray-on fireproofing was innovative and not consistent with then-prevailing practice.

- **No evidence of technical basis in the selection of fireproofing thickness** to meet 2 h fire rating:
  - 1/2 in. specified when WTC towers were built (Expectation IA, not IB)
  - 1-1/2 in. specified for upgrades some years prior to 2001
  - 2 in. for similar floor system in an unrestrained test (model code evaluation service recommendation in June 2001, unrelated to WTC buildings)

- **No evidence that full-scale fire resistance test of the WTC floor system was conducted** to determine the required fireproofing thickness; in 1966, the Architect of Record and, in 1975, the Structural Engineer of Record stated that the fire rating of the WTC floor system could not be determined without testing.

NYC Building Code Provisions (Fire Resistance in hours)

	1938	1968*	2001**
Columns	4	3	2
Floors	3	2	1-1/2

*** Building code governing original design and occupancy**
**** Sprinklers required for buildings of unlimited height**

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Fireproofing Thickness in NIST-Sponsored Tests at UL

Condition	Primary Trusses	Bridging Trusses	Metal Deck
Original Specified	1/2 in	0 in	No Overspray
As-Applied	3/4 in	3/8 in	Overspray

- Three tests were conducted in the as-applied condition:
  - 35-foot span; restrained test
  - 35-foot span; unrestrained test
  - 17-foot span; restrained test
- One test was conducted in the original specified condition:
  - 17-foot span; restrained test

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Results From NIST-Sponsored Tests at UL

Test	Description	Times to Reach End-Point Criteria (min)					Test Termin-ated (min)	Standard Fire Test Rating		
		Temperature on Unexposed Surface		Steel Temperatures		Failure to Support Load		ASTM E 119-61	ASTM E 119-00	
		Average (Ambient +250°F)	Maximum (Ambient +325°F)	Average (1100°F)	Maxi-mum (1300°F)			Rating (hr)	Restr-ained Rating (hr)	Unrestr-ained Rating (hr)
1	35 ft, restrained, ¾ in fireproofing	---	111	66	62	(3)	116(1)	1½	1½	1
2	35 ft, unrestrained, ¾ in fireproofing	---	---	76	62	(3)	146(2)	2	---	2
3	17 ft, restrained, ¾ in fireproofing	180	157	86	76	(3)	210(2)	2	2	1
4	17 ft, restrained, ½ in fireproofing	---	58	66	58	(3)	120(1)	¾	¾	¾

(1) Imminent collapse
(2) Vertical displacement exceeded capability to measure accurately
(3) Did not occur

The end-point criterion that determined the rating is shown in matching color.

Findings of Standard Fire Resistance Tests

- The test structures were able to withstand standard fire conditions for between 45 minutes and 2 hours. The floor system did not fail to support loads in all tests.
- The 1968 New York City building code—the code that the WTC towers were intended but not required to meet when they were built—required a 2-hour fire rating for the floor system.
- **The 45-minute fire resistance for the standard 17-foot test with the specified 0.5 inch fireproofing did not meet the 2-hour requirement of the NYC building code.** This test had no fireproofing on the bridging trusses and on the underside of the metal deck.
- **The 2-hour fire resistance for the standard 17-foot test with the as-applied average 0.75 inch fireproofing met the 2-hour requirement of the NYC building code.** This test had half the fireproofing thickness on the bridging trusses and overspray on the underside of the metal deck.
- **The possible cause of the difference in test results is not due to the fireproofing thickness on the trusses, but due to moisture content differences in the concrete deck and the presence or lack of fireproofing overspray on the underside of the metal deck.**

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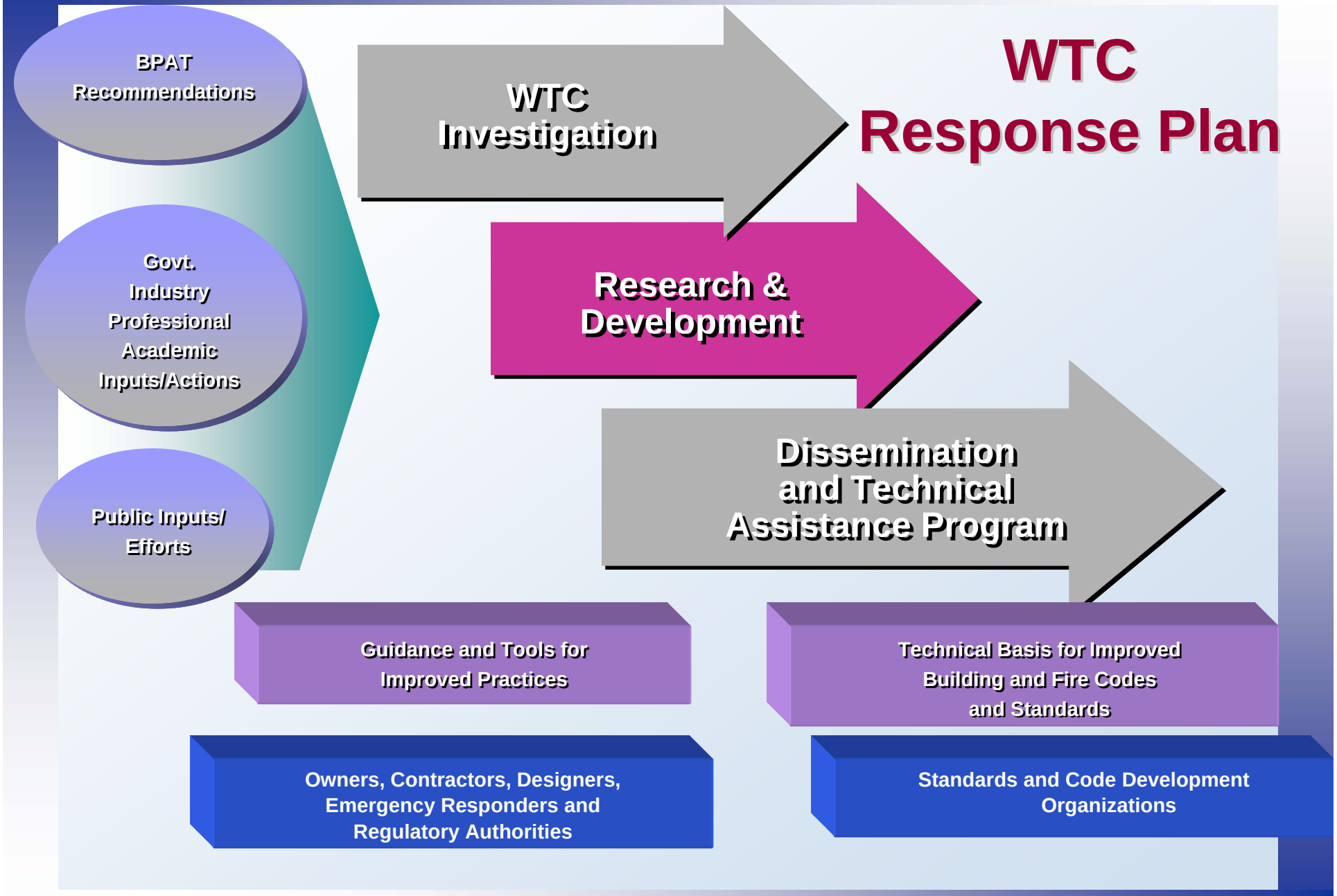
WTC Response Plan



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Safety of Threatened Buildings R&D Program

Increased Structural Integrity

Prevention of Progressive Collapse

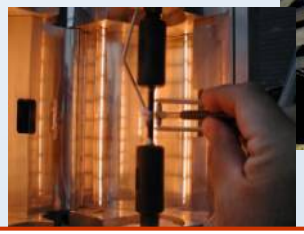
To develop and implement performance criteria for codes and standards, tools, and practical guidance for prevention of progressive structural collapse.

Fire Safe Building Structures

To develop and implement verified and improved standards, tools, methodology and guidance for the fire safety design and retrofit of concrete and steel structures.

Enhanced Fire Resistance

Fire Protective Coatings for Structural Steel - Predictive criteria for selection of fire protective coatings to accelerate development of materials with reduced vulnerability to extreme events.



Fire Resistance of Structural Steel - Develop efficient test method for evaluating fire resistance of steel; Benefits of FR steel not adequately tested under ASTM E119

Fire Resistance of Building Partitions

Technical basis for accurate measurement & prediction methodologies for inclusion of fire resistance properties of walls,floors & ceilings in performance-based fire safety design

NIST

Safety of Threatened Buildings R&D Program

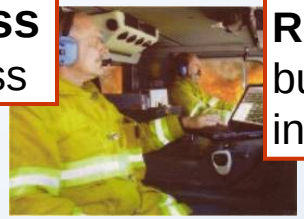
Improved Emergency Egress & Access

Occupant Behavior and Egress
Reliable predictions of time to egress

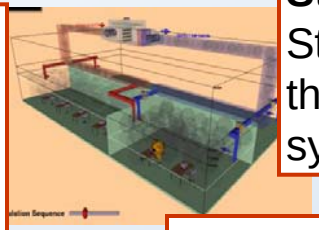
Emergency Use of Elevators
Technical and procedural means to allow use of elevators during emergencies for evacuation of occupants with disabilities from, and for first responder access to, high rise buildings

Building & Emergency Equipment Stds & Guidelines

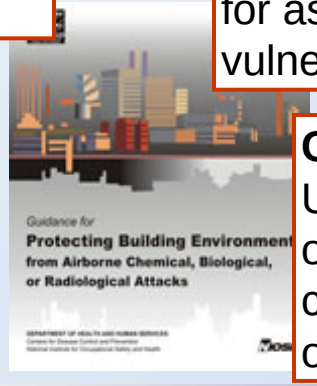
Equipment Standards for First Responders - Technologies that enhance building information transfer to support informed fire fighting decisions



Standard Information Models
Standard building information models that facilitate simulation of building system behavior during adverse events



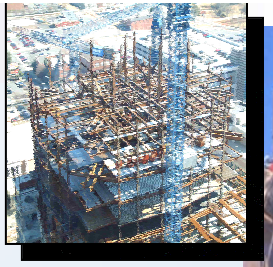
Technologies for Building Operations in CBR Attacks - Analysis tools and guidance for assessment and subsequent reductions in vulnerability of buildings to CBR attacks



Cost-effective Risk Management Tools
User-friendly tool for building owners/managers to aid in selection of cost-effective strategies for management of terrorist and environmental risks

NIST

Dissemination and Technical Assistance Program



- **Concept:**
  Engage leaders of the construction and building community in assuring timely implementation of needed changes to practices, standards, and codes.

- **Functions:**
  Provide inputs and participate in developing best practices, guidance and tools for vulnerability assessment and reduction, guidance on standards and codes needs.

  Represent public interest.

  Timely adoption, dissemination, and use of investigation recommendations and R&D outputs.

- **Partners:**
  Codes and standards developers, e.g., ICC, NFPA, ASME, ASTM...
  Professional, engineering organizations, e.g., IAFC, ASCE, SFPE, AIA, AGC...
  Industrial/trade bodies, e.g. CII, FIATECH, CERF, NIBS,…

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